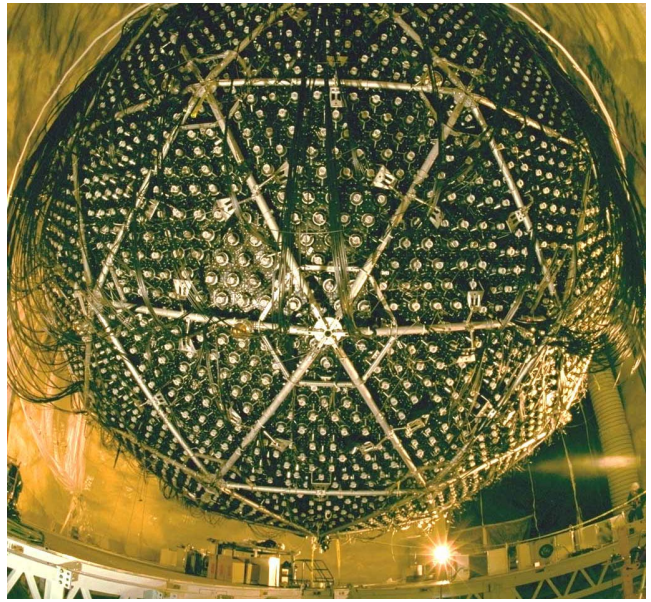
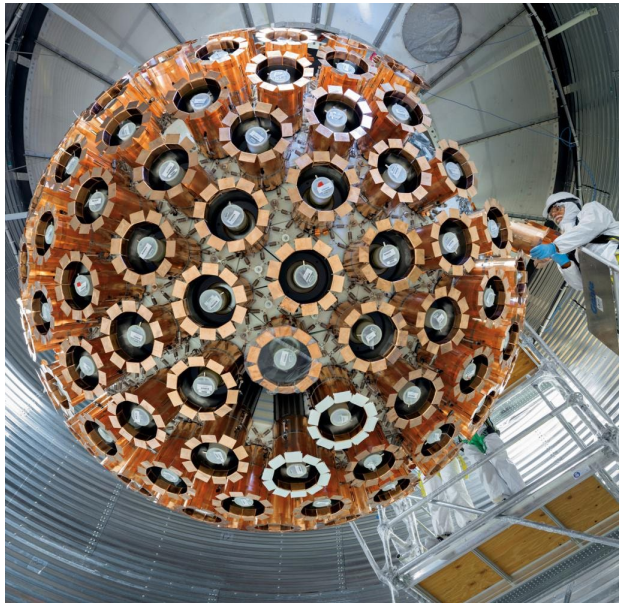
International Scientific Cooperation to Answer Existential Questions on the Origin and Evolution of the Universe





Art McDonald, Queen's University, Kingston, Canada

Nobel Physics Laureate 2015

International Peace Foundation, Taiwan

Tamkang University, March 9, 2026

International Scientific Cooperation to Answer Existential Questions on the Origin and Evolution of the Universe

- **Scientists cooperate openly across the world, largely independent of political restrictions, to address basic questions of how our world works.**

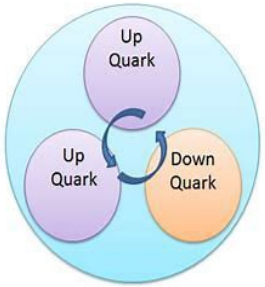
- **During the past ~60 years, we have developed a detailed picture of how the Universe has evolved since the Big Bang, producing everything we experience in our world: ANSWERING THE EXISTENTIAL QUESTION: WHERE DID THIS UNIVERSE COME FROM?**

- **I believe that world governments could learn from the remarkable degree of cooperation among basic scientists, who are motivated by a common interest in understanding our world as completely as possible.**

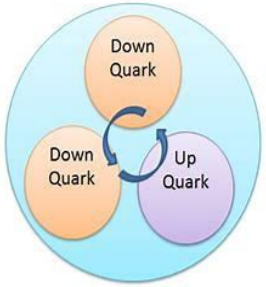
- **Could we find such a common interest that could motivate international governments to cooperate as scientists do?**

Standard Model for Elementary Particles

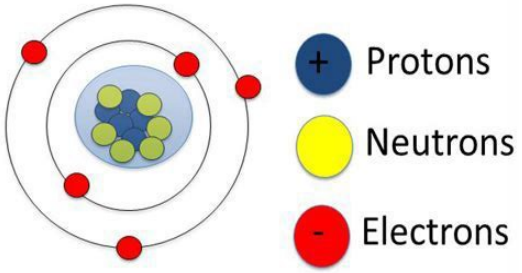
Proton

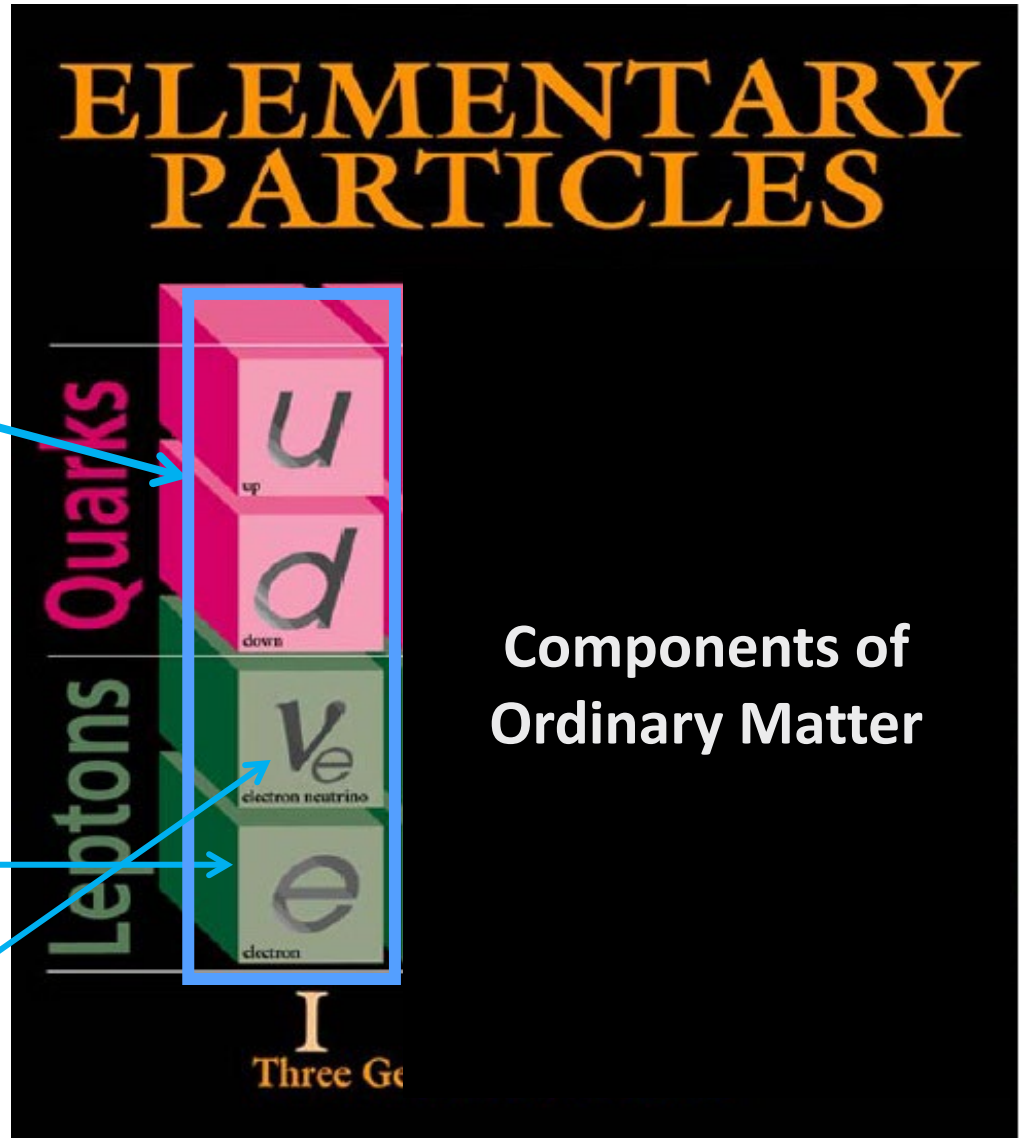


Neutron



Atom





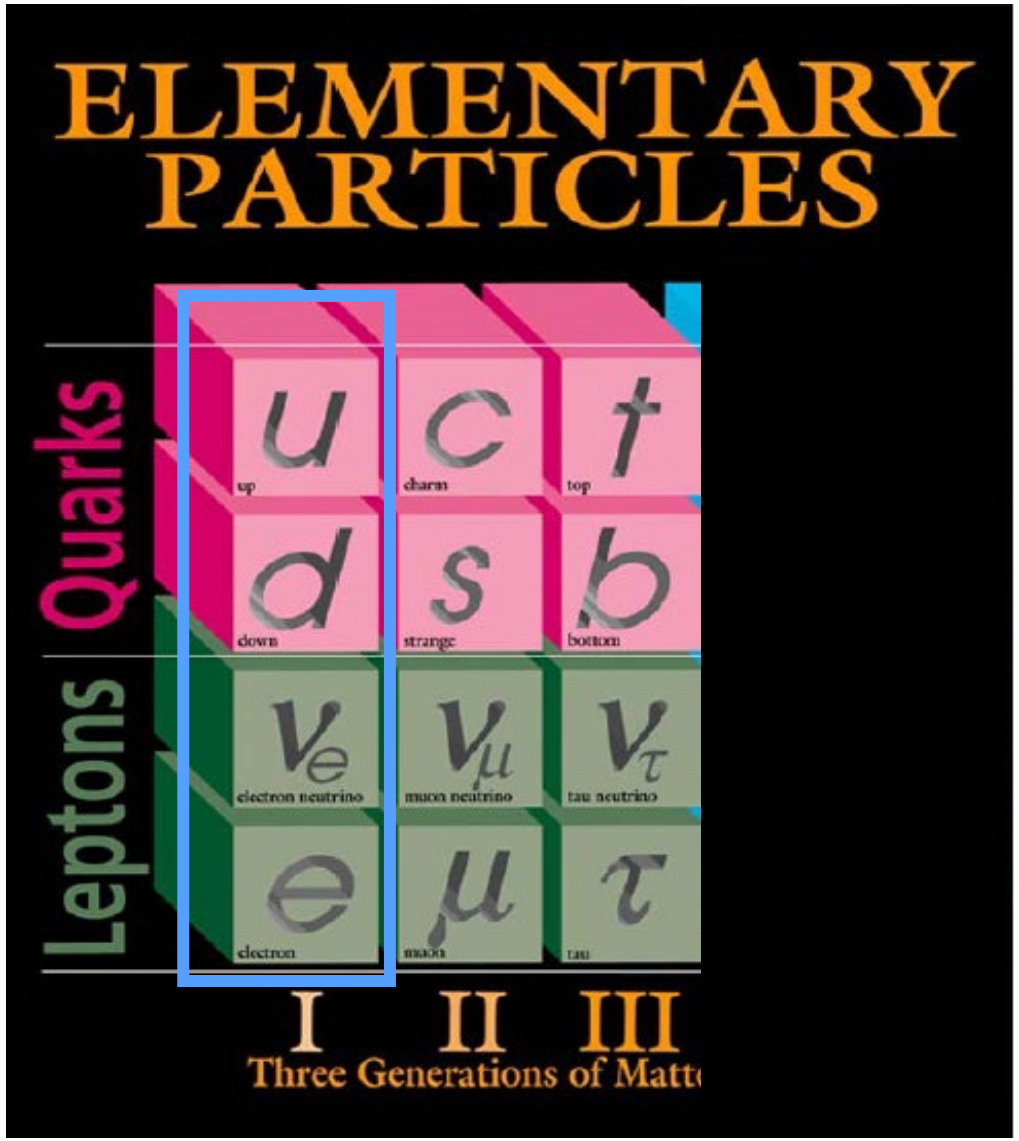
Components of Ordinary Matter

+ Higgs Boson

Neutrinos are emitted in some radioactive decays and in nuclear reactions in the sun and supernovae.

Standard Model for Elementary Particles

Full set of particles in the Standard Model, including heavier ones observed in Cosmic Rays and accelerator experiments

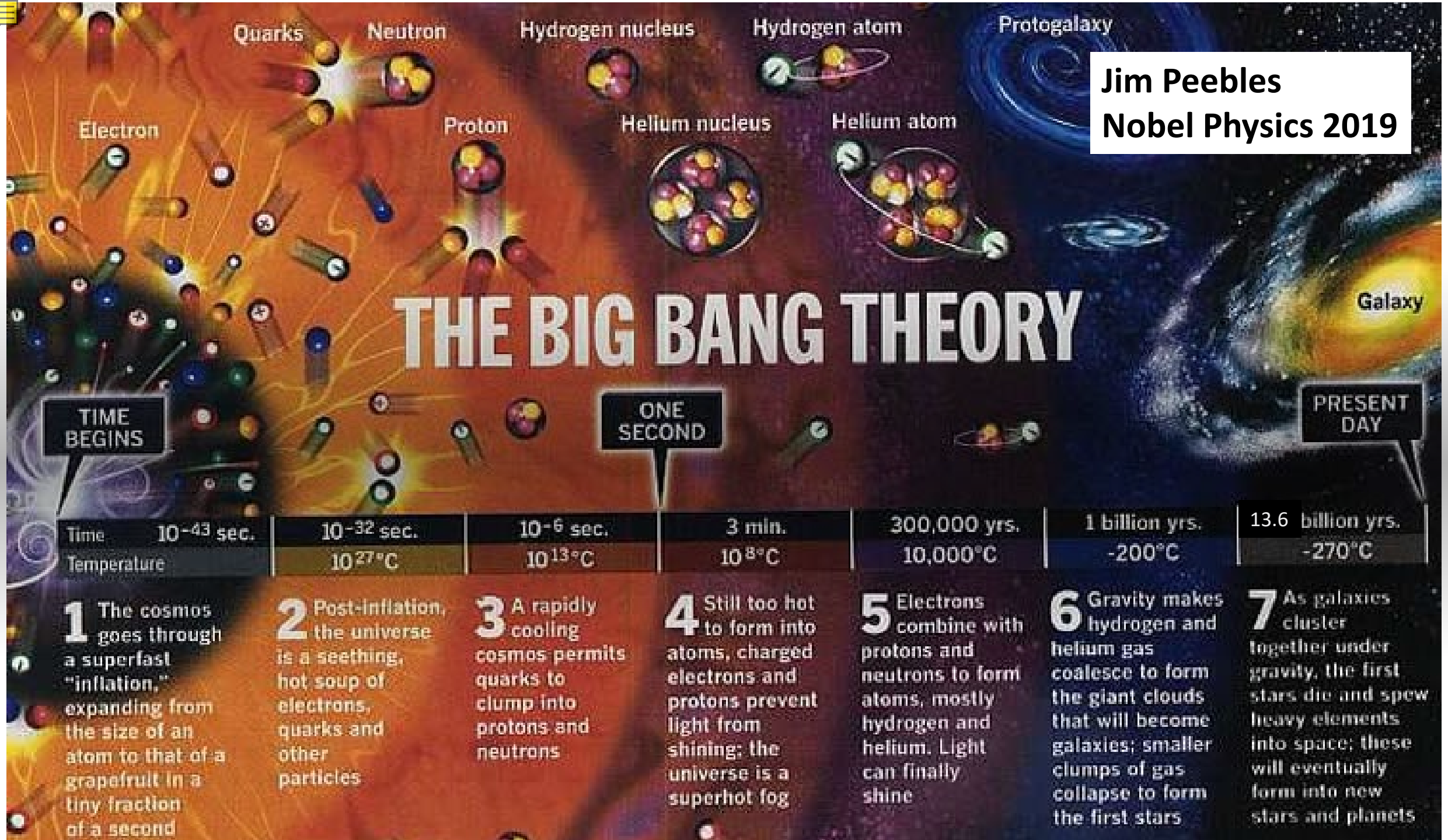


ANTI-MATTER

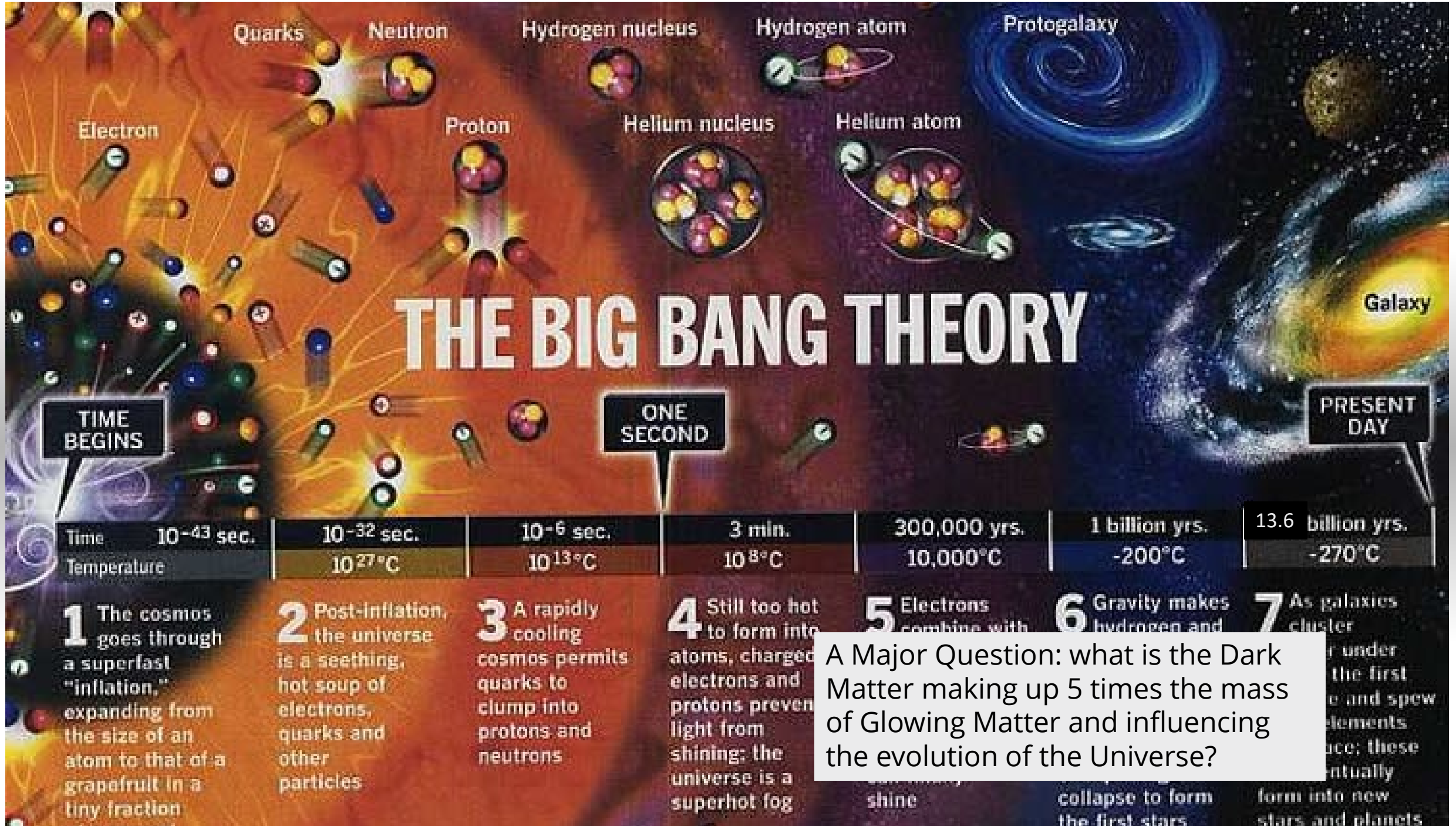
Each of the matter particles has an equivalent anti-matter partner. When they come together they annihilate each other leaving pure energy. The opposite occurs when pure energy is converted to matter and anti-matter in the Big Bang.

+ Higgs Boson

DARK MATTER IS DIFFERENT FROM ANY PARTICLE THAT WE HAVE EVER SEEN: A NEW FORM OF MATTER!!



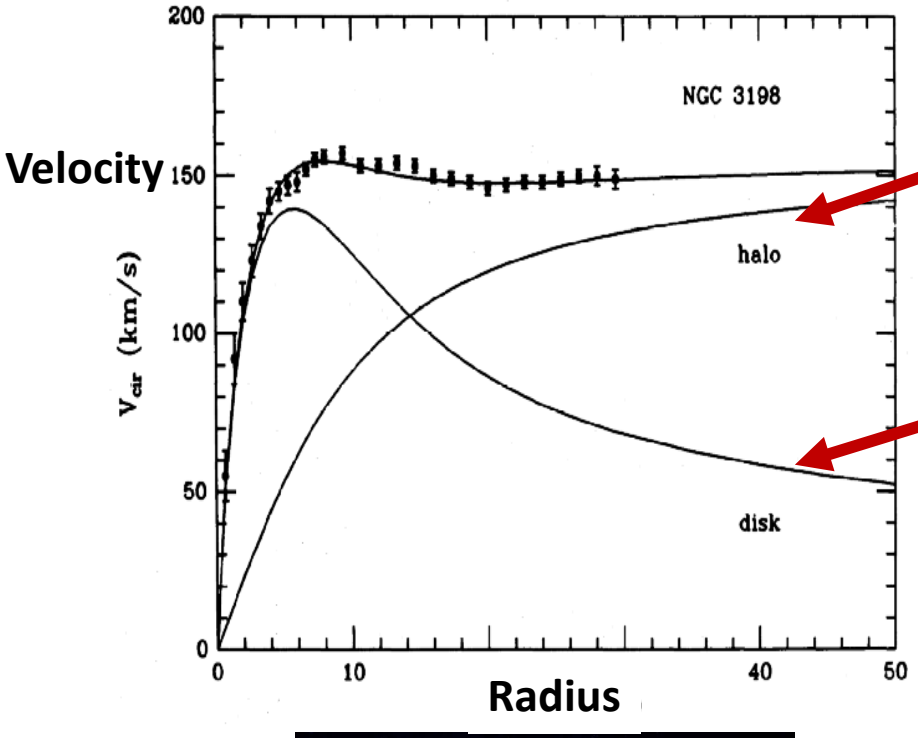
Jim Peebles
Nobel Physics 2019



A Major Question: what is the Dark Matter making up 5 times the mass of Glowing Matter and influencing the evolution of the Universe?

The strong evidence for dark matter from astrophysics measurements

Distribution of stars in a spiral Galaxy like ours



DARK MATTER

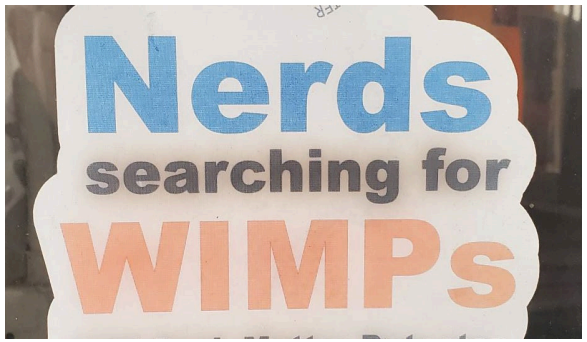
GLOWING MATTER

Spiral galaxies, like our milky way would fly apart if composed of only the glowing matter

It is found that the amount of Dark Mass is about five times that of Glowing Mass in our Galaxy. Similar things are found throughout the Universe

Putting this and much more evidence together, one concludes that one way to describe Dark Matter particles is:

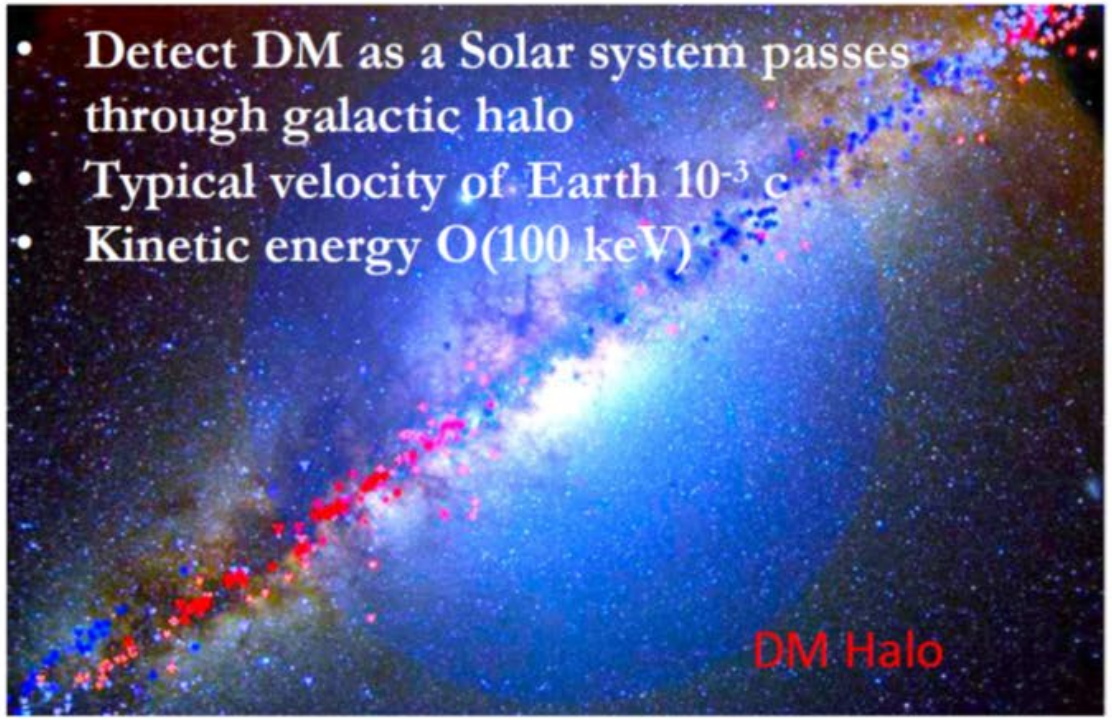
Weakly Interacting Massive Particles (WIMPS)

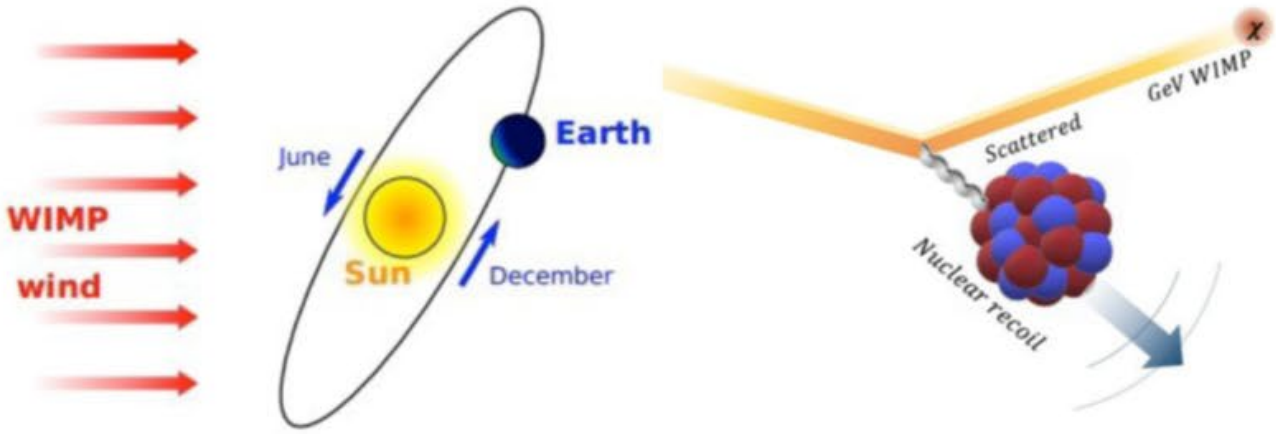


Sign outside student's offices at Queen's University

DARK MATTER direct detection

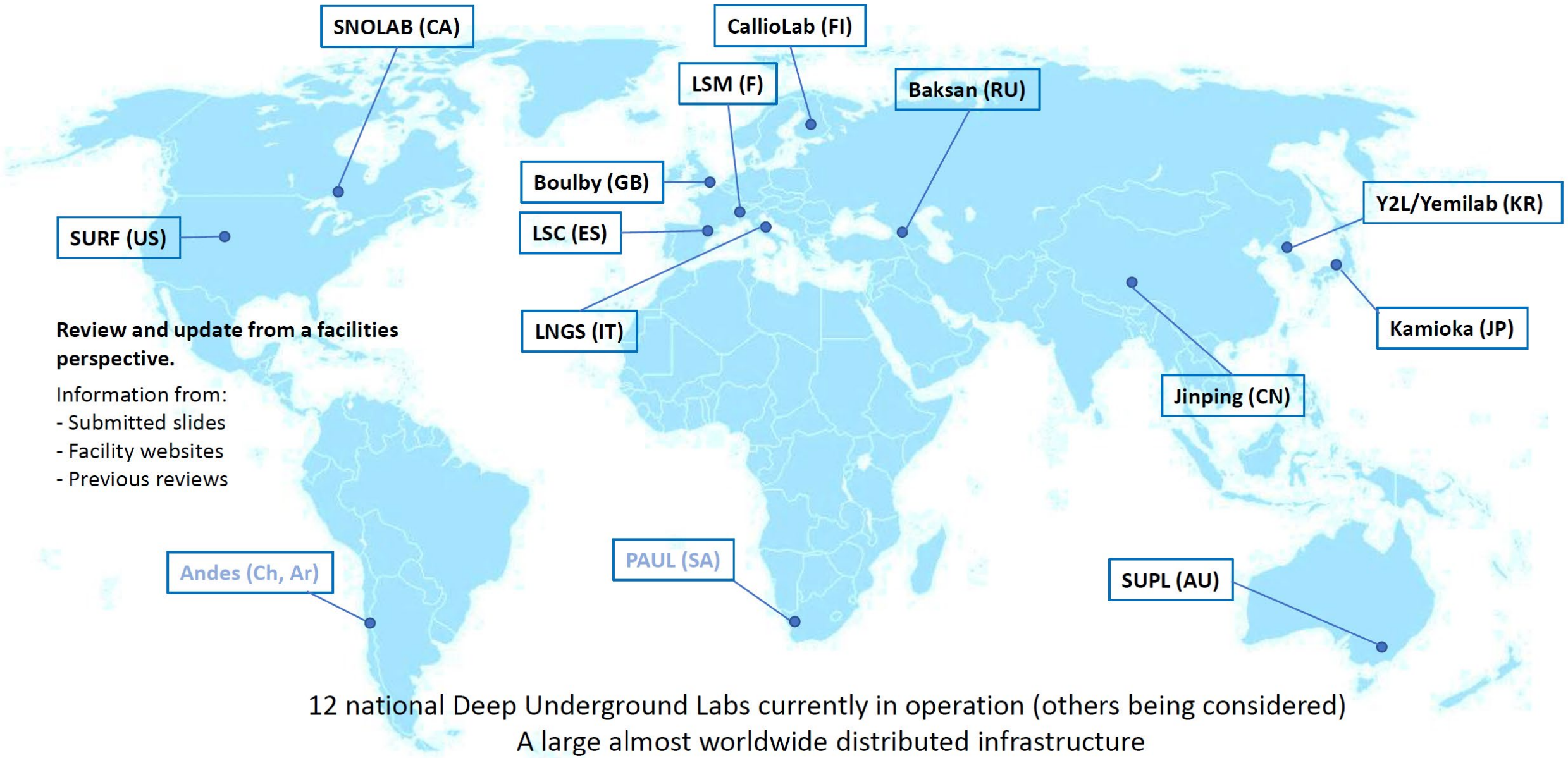
- **As we pass through the Dark Matter that is holding our Galaxy in its present form, WIMPs could hit atoms in our detector and they would recoil like a billard ball.**
- **Detectors use Xenon, Argon, He, Fluorine, Silicon, Germanium to look for WIMPS hitting nuclei**





Detection signal: nuclear recoil (NR)

World Deep Underground Science Labs



Review and update from a facilities perspective.

Information from:
- Submitted slides
- Facility websites
- Previous reviews

12 national Deep Underground Labs currently in operation (others being considered)
A large almost worldwide distributed infrastructure

SNOLAB

Canada

DEAP 3600 kg Dark Matter (Ar),
NEWS-G: Dark Matter (He, Ne)
PICO-500: Dark Matter (F)

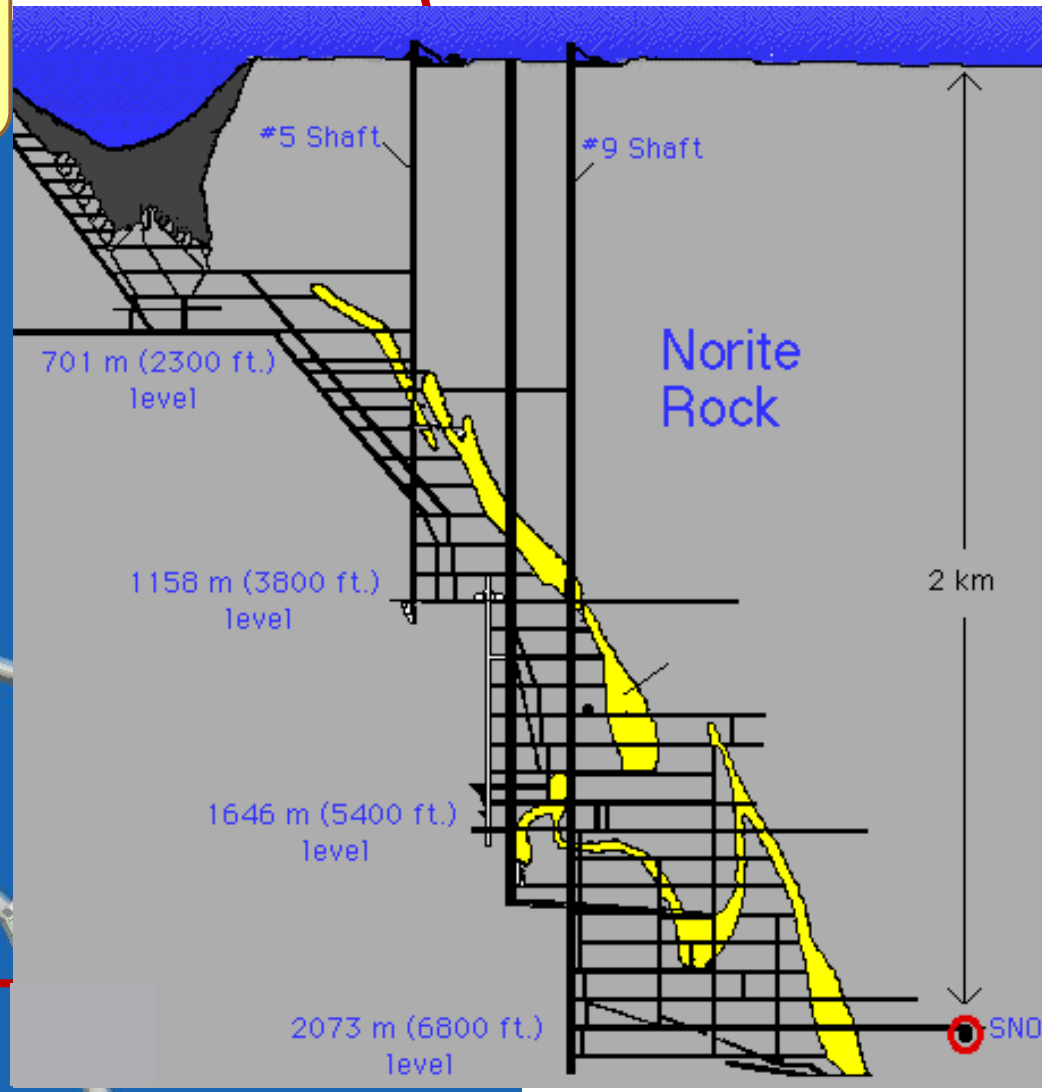
New large project.

PICO-40: Dark Matter (F)

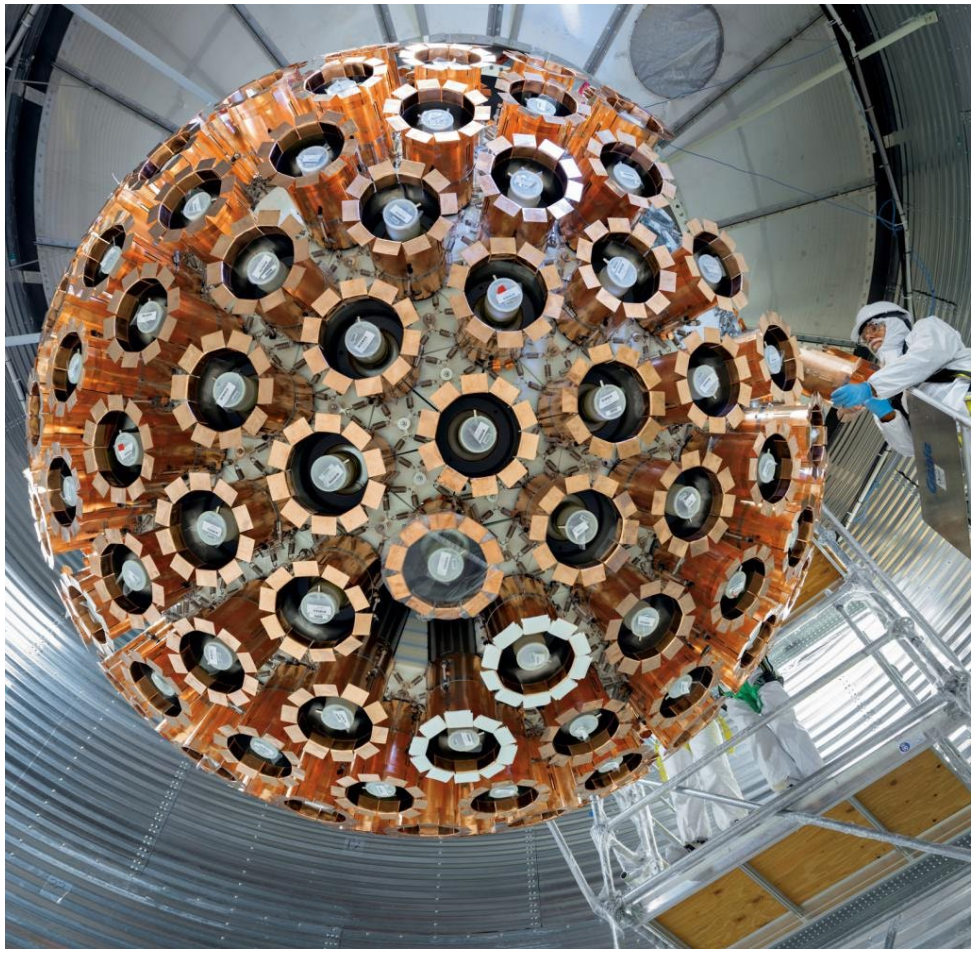
SENSEI:Dark Matter (Si)

SNO+: Neutrinoless Double Beta, solar,geoneutrinos

SuperCDMS Dark Matter (Si, Ge)
NEW: Leading Sensitivity to LOWER MASS DARK MATTER



DEAP – 3600

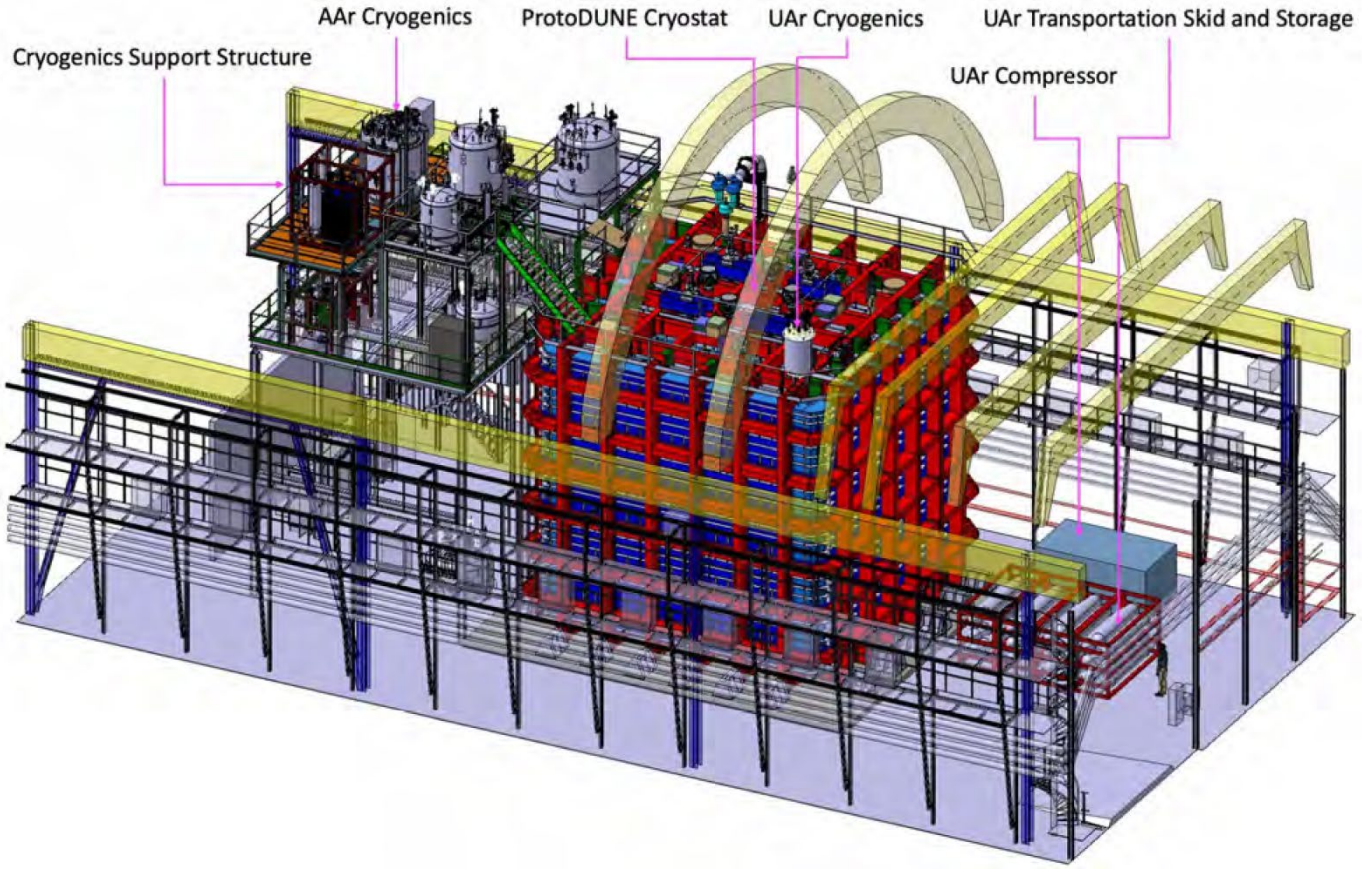


3000 kg Liquid Argon core:

- **DARK MATTER generates light in 10 nanoseconds. Gamma, Beta Radioactivity takes 500 times longer.**
- **STRONG Discrimination against local radioactivity.**
- **Many international experiments: Nothing observed so far, but limits for DARK MATTER interactions with matter improved by more than 10,000 times, mainly by Xenon-based experiments.**

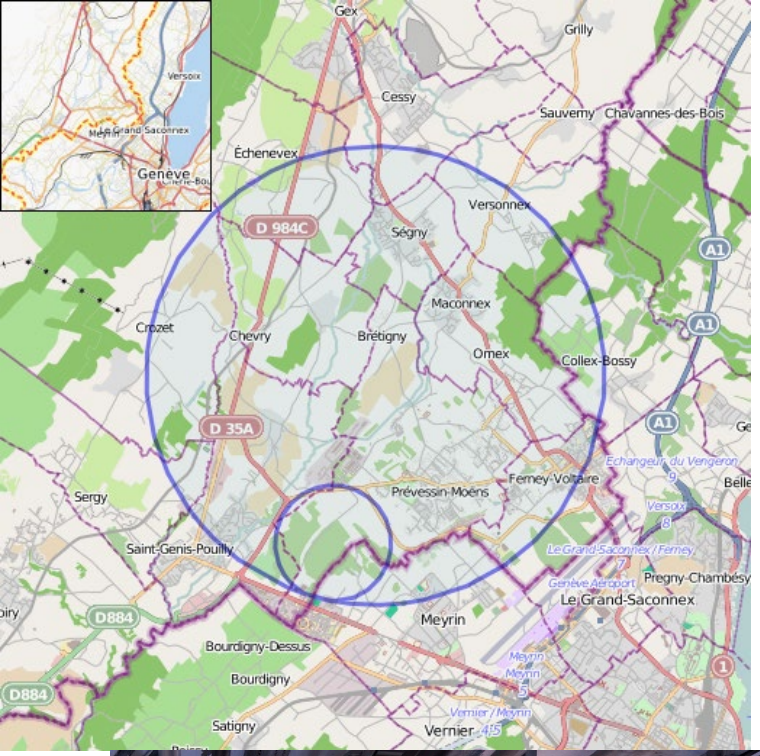
Dark-Side 20k – Gran Sasso, Italy

The DarkSide-20k experiment under construction will use 20 tons of liquid argon to search for Dark Matter. The international collaboration includes over *400 scientists from 14 countries*.



LNGS Hall C

Extensive progress on sensitivity has been made by Xenon-based experiments LZ (US), PandaX (China) and Xenon (Italy)

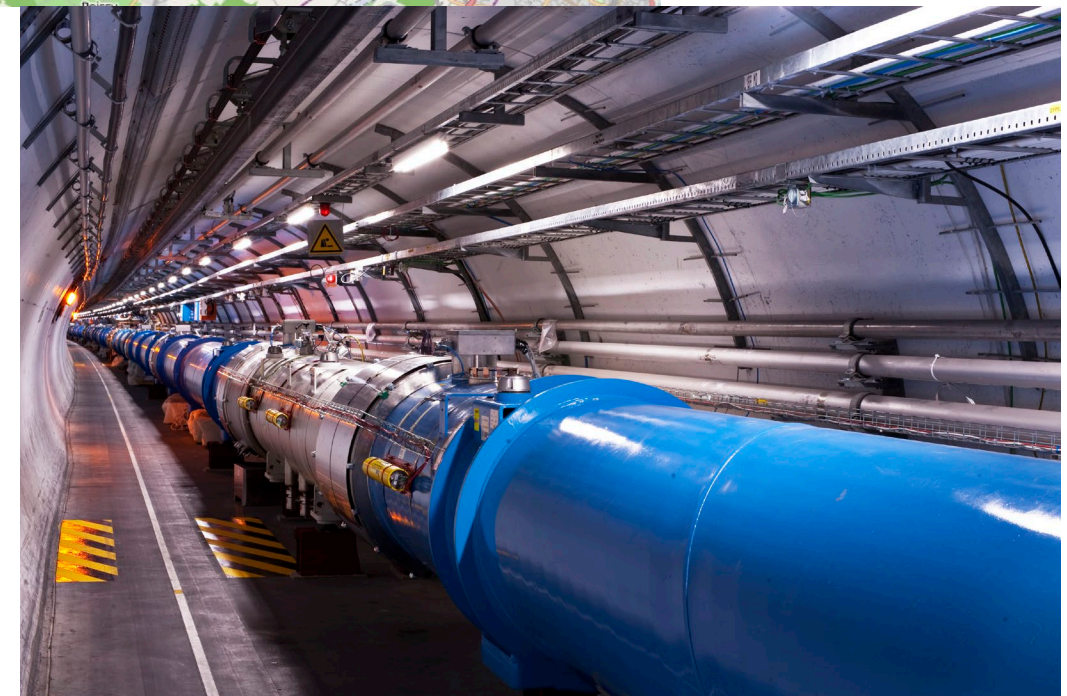


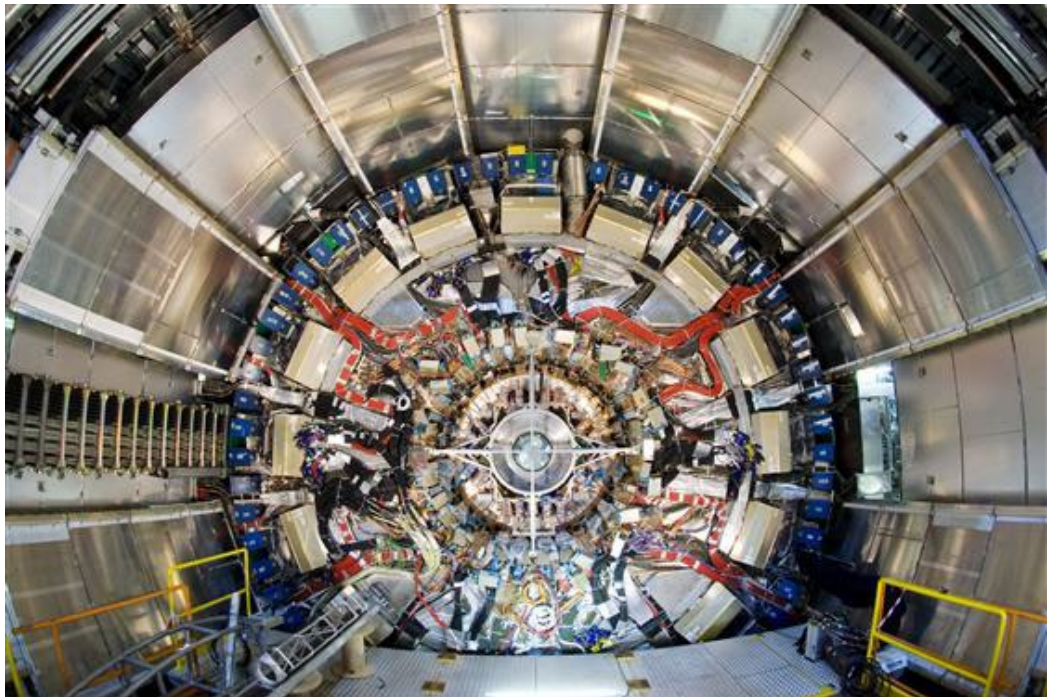
CERN (Geneva)

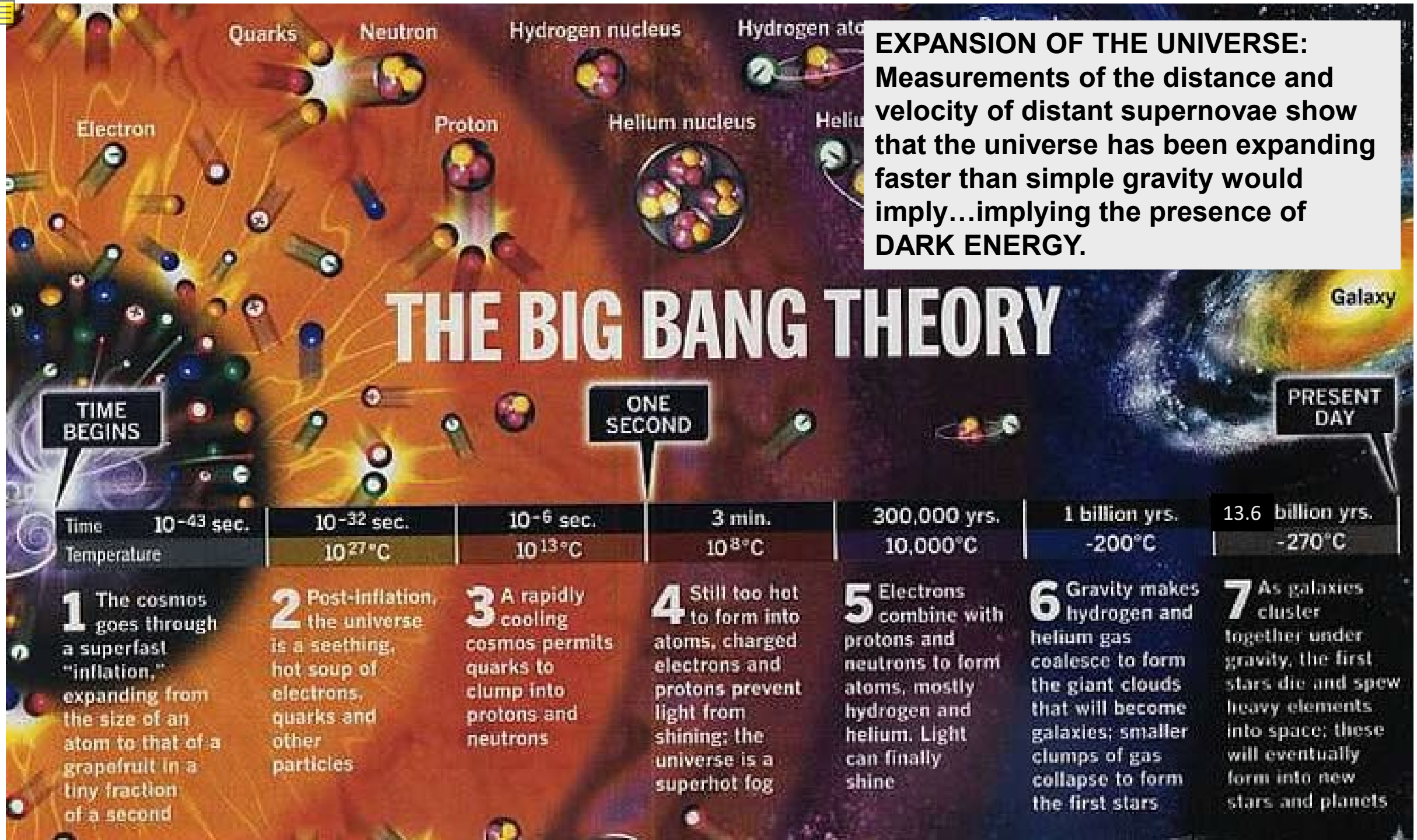
24 Member States, 10 Associate Members, 50 states with Cooperation Agreements or observer status, 12,000 international scientists.

CERN is attempting to create Dark Matter particles for the first time since the Big Bang.

There are also many telescopes and satellite-borne astronomical experiments looking for massive Dark Matter particles and other searches for axion-like lighter particles.

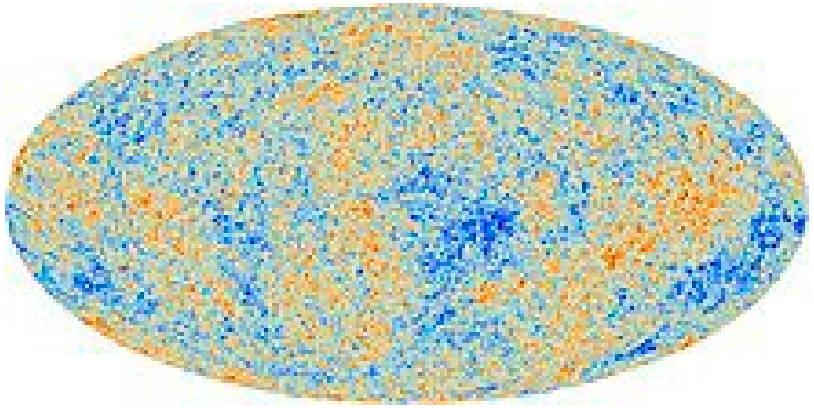






EXPANSION OF THE UNIVERSE: Measurements of the distance and velocity of distant supernovae show that the universe has been expanding faster than simple gravity would imply…implying the presence of DARK ENERGY.

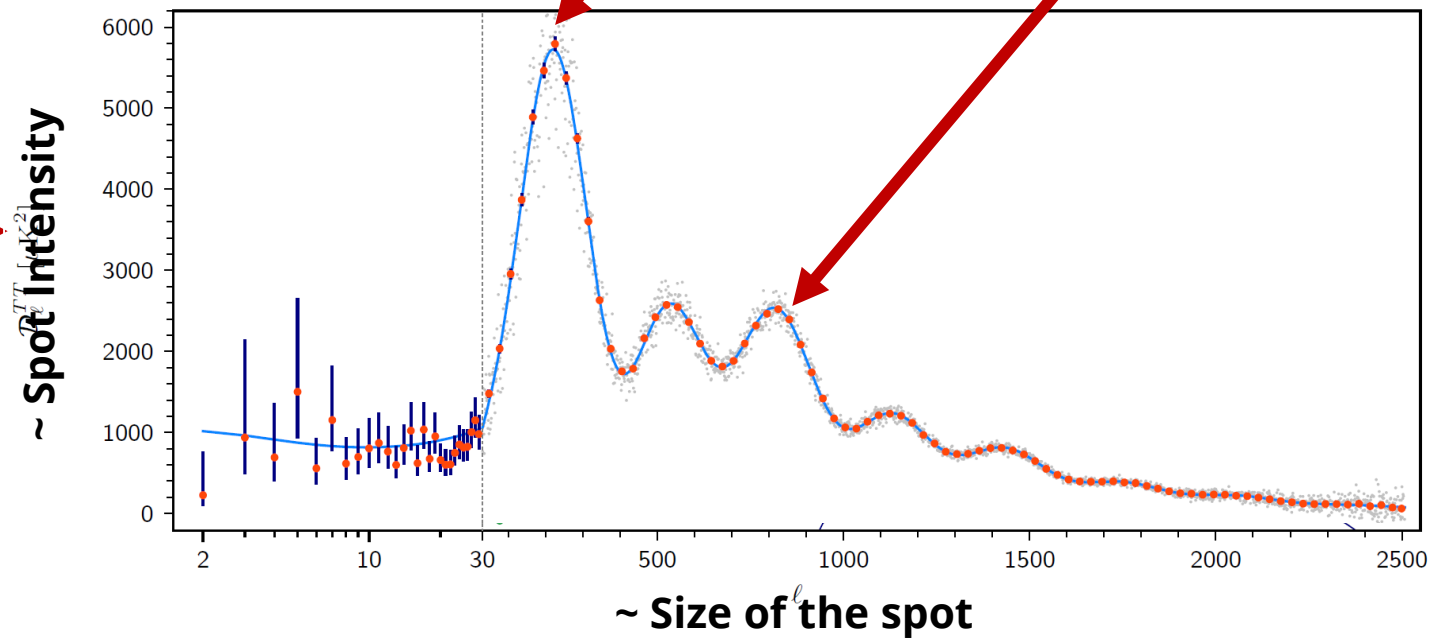
Cosmic Background Radiation (300,000 years after Big Bang)



Mainly Influenced by Ordinary Matter

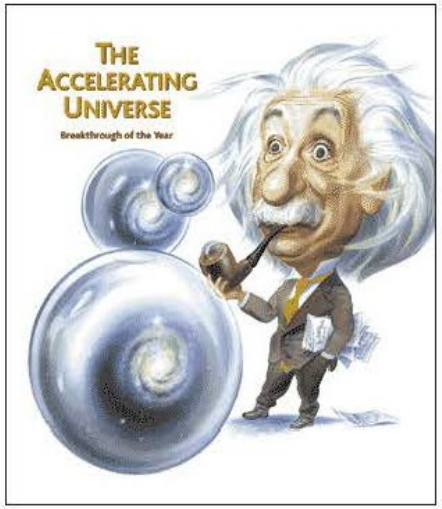
Largely influenced by Dark Matter

Angular Power Spectrum from Planck Satellite fit by Cosmology Model

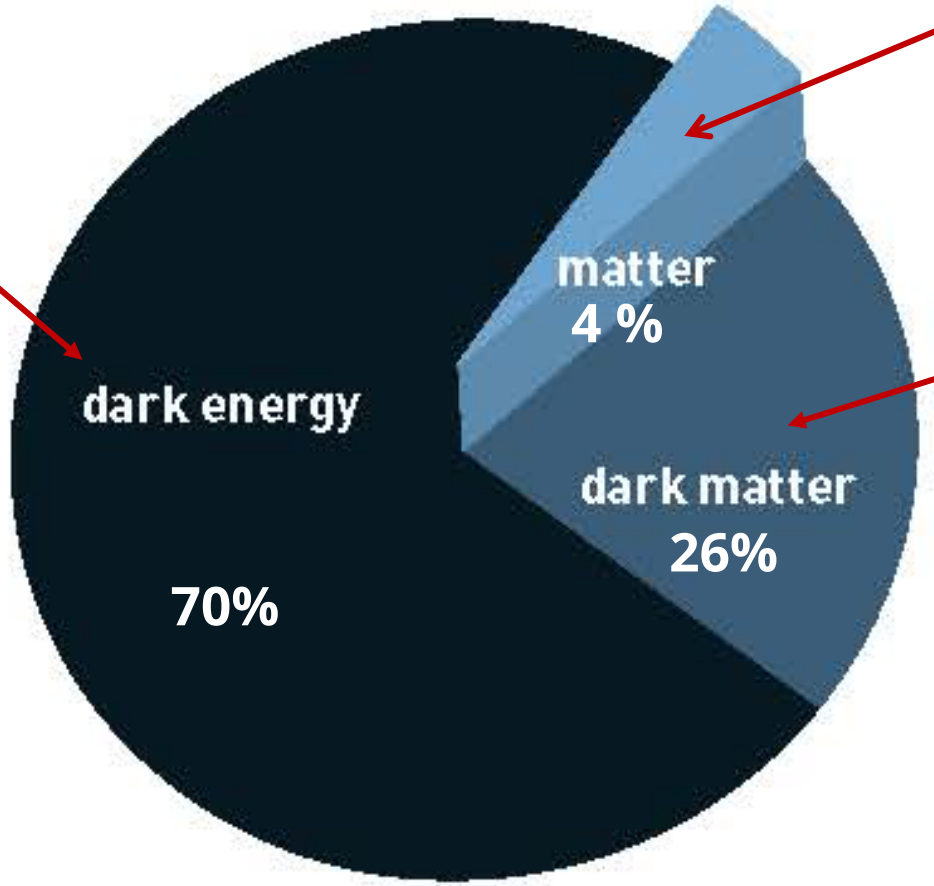


The Blue Line is a fit based on the theory, 6 parameters, including Matter, Dark Matter and Dark Energy

Composition of the Universe as we understand it today

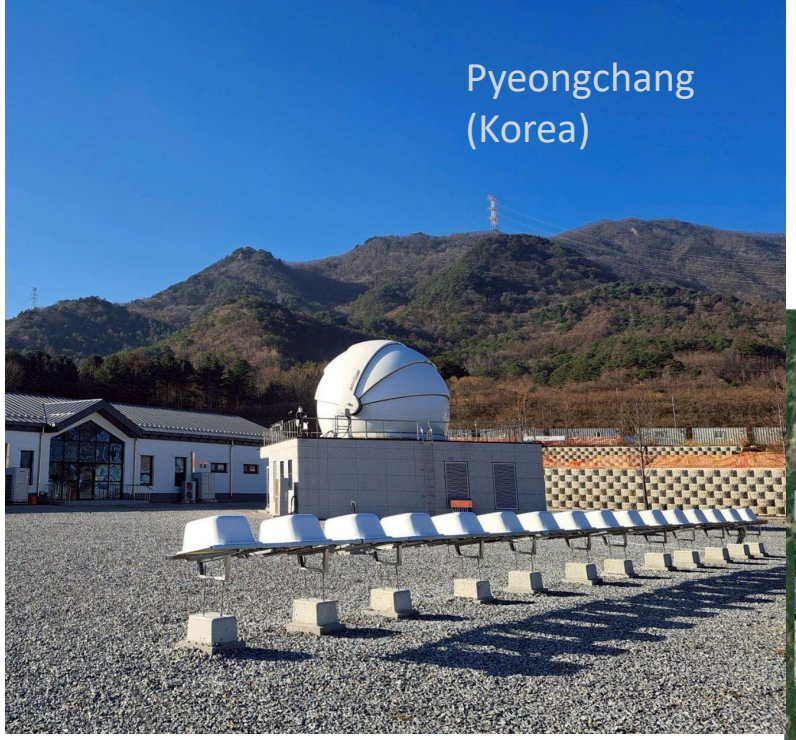


Responsible for accelerating the Universe's expansion



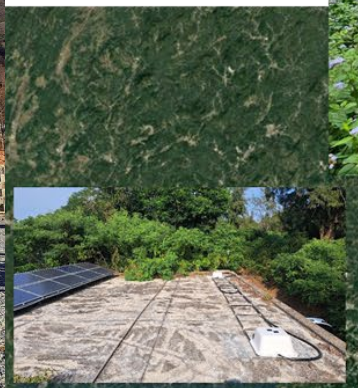
The Stars and US!!!

Neutrinos Are only a few %



New Astronomy measurements

TKU Lanyang upgrade



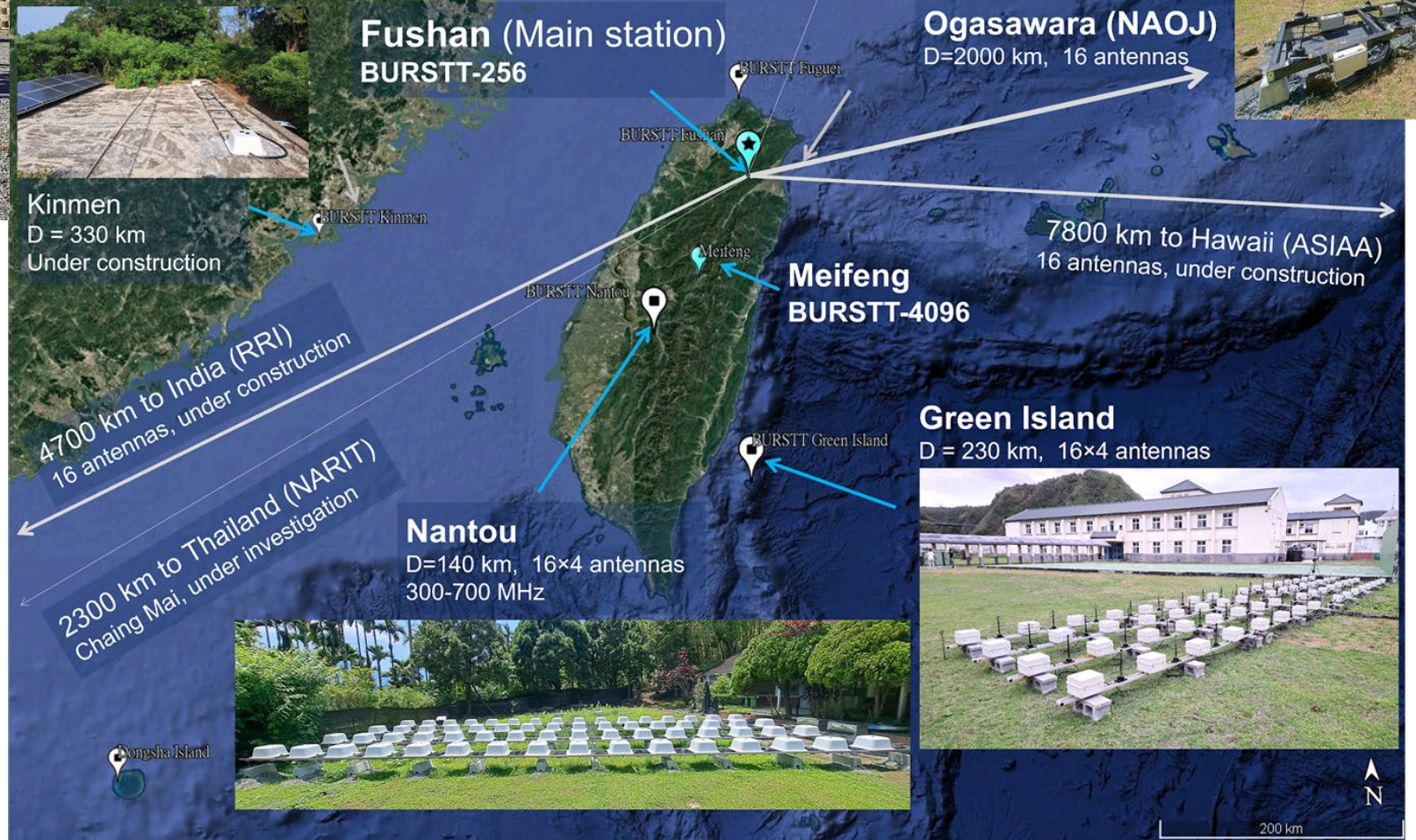
BURSTT: Taiwan-regional

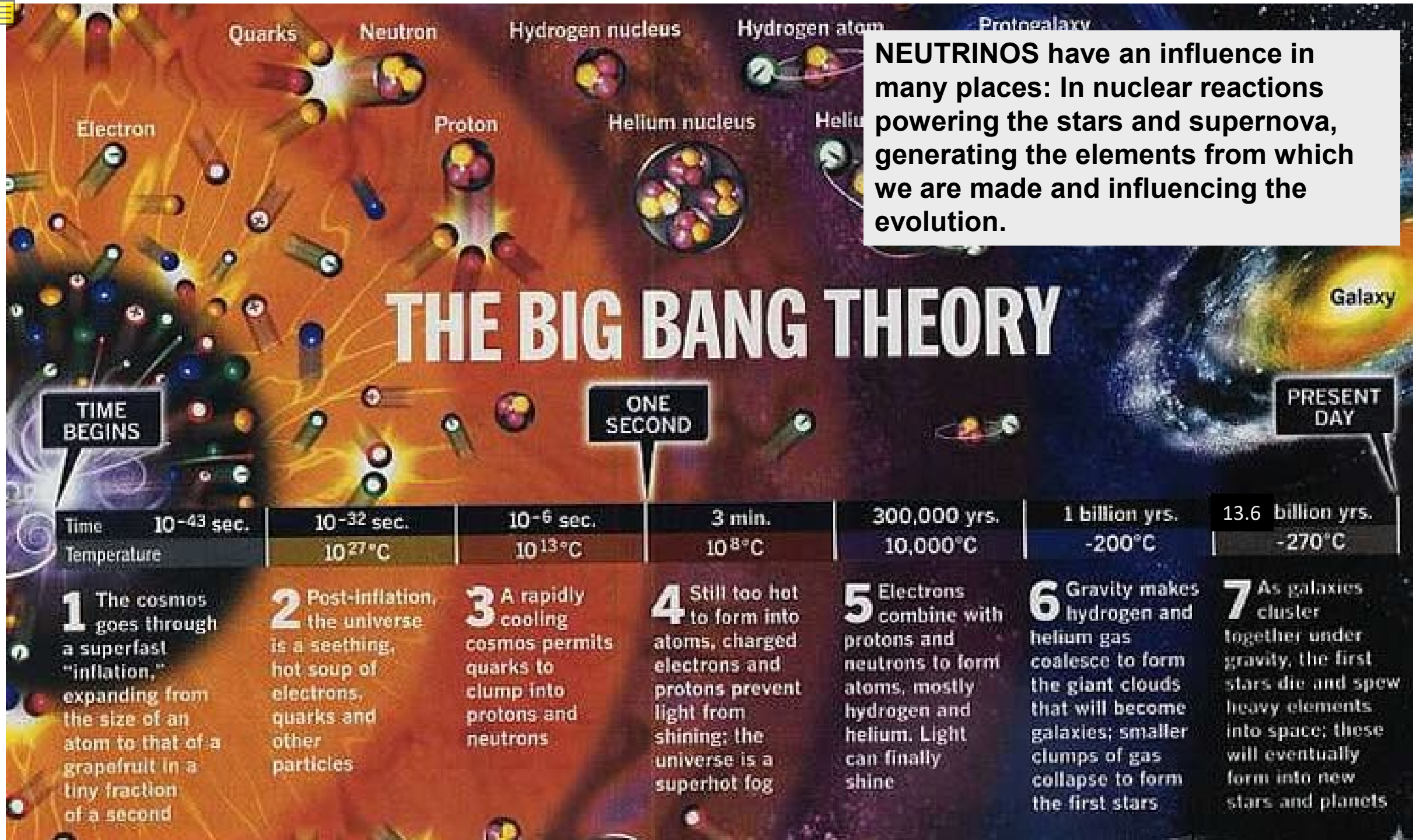
all-sky radio telescope: Taiwan, India, Korea, Japan, Thailand.
5 universities +4 Institutes
Taiwan:ASIAA, NTU, NTHU, NCHU, TKU (Prof. Chin)

FAST RADIO BURSTERS

Revolutionary all-sky coverage

Magnetars? Compact mergers?



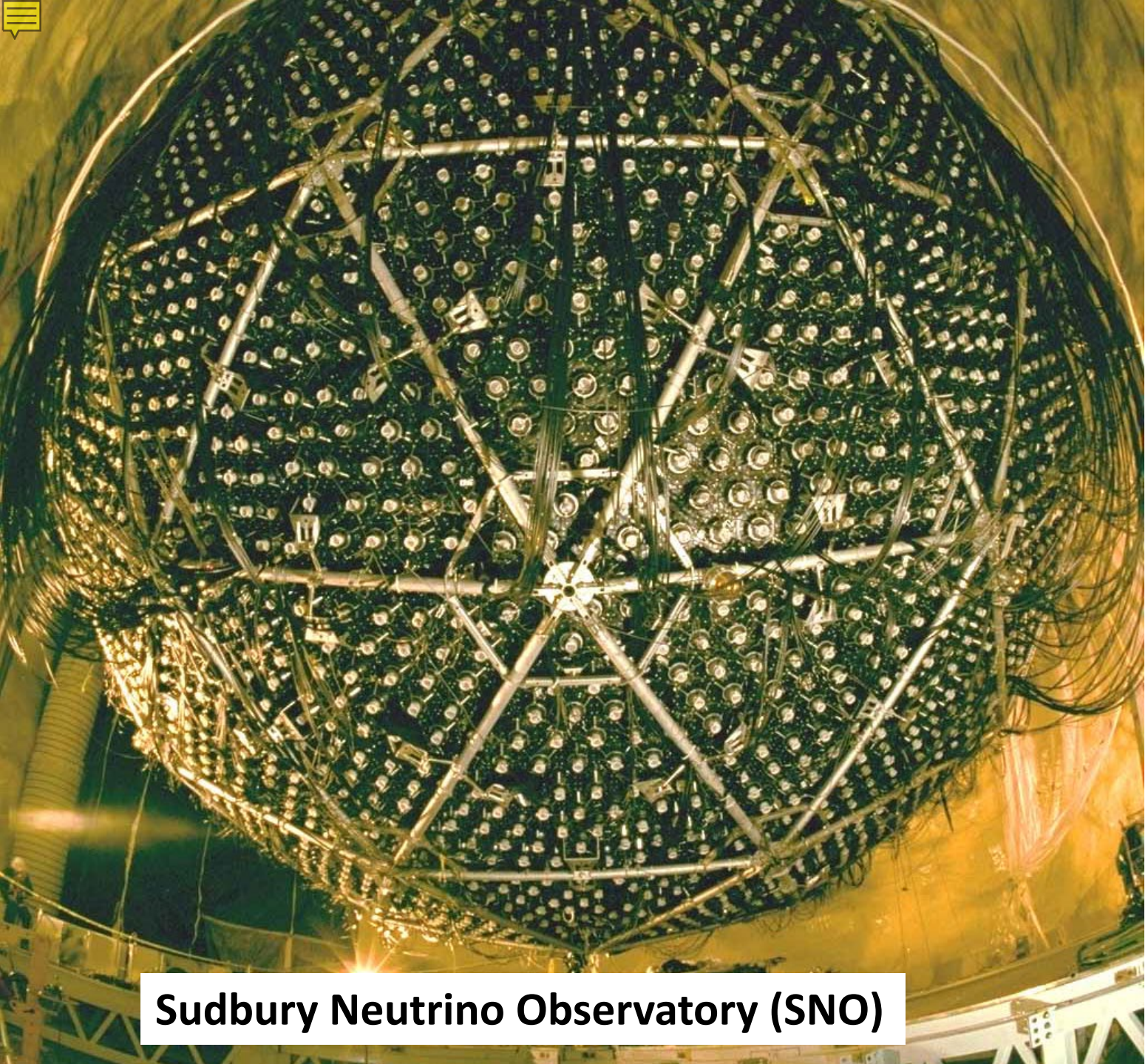


NEUTRINOS have an influence in many places: In nuclear reactions powering the stars and supernova, generating the elements from which we are made and influencing the evolution.

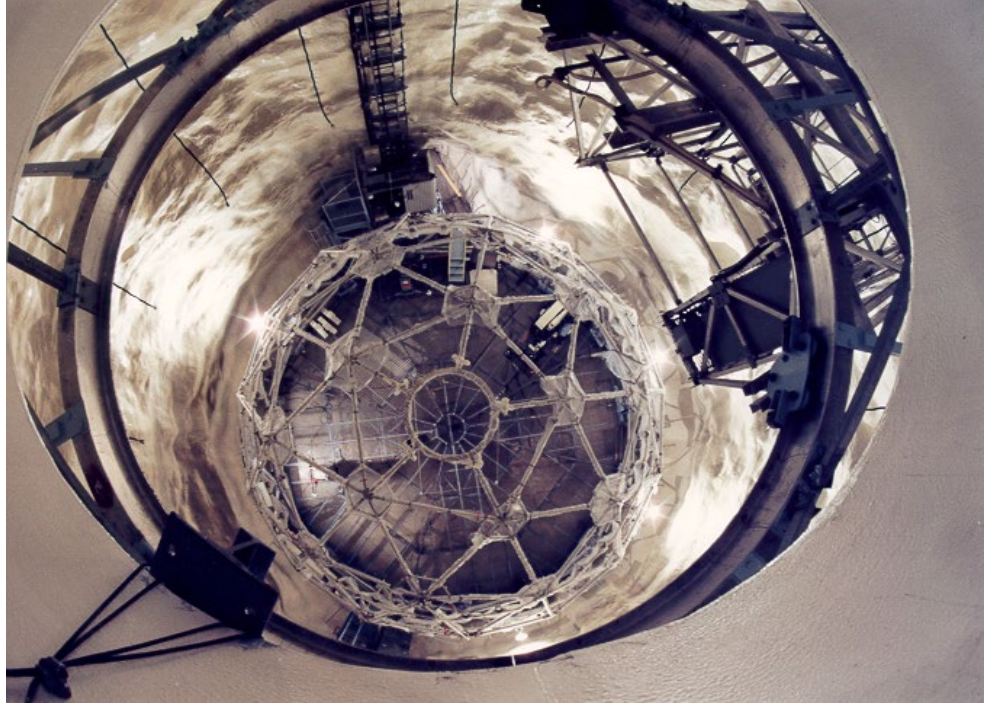
Neutrino Facts

- **Neutrino only feel the Weak Force**
- **They are very difficult to detect but easily leave the sun.**
- **We had to build a detector the size of a ten-storey building to observe one per hour from the sun**
- **Discovery : The Standard Model said that they should not change their flavour or oscillate between flavours. With the SNO experiment, we found that they change their flavour, requiring additions to the Standard Model and implying that they have a rest mass greater than zero.**

Illustration: © Johan Jarnestad/The Royal Swedish Academy of Sciences

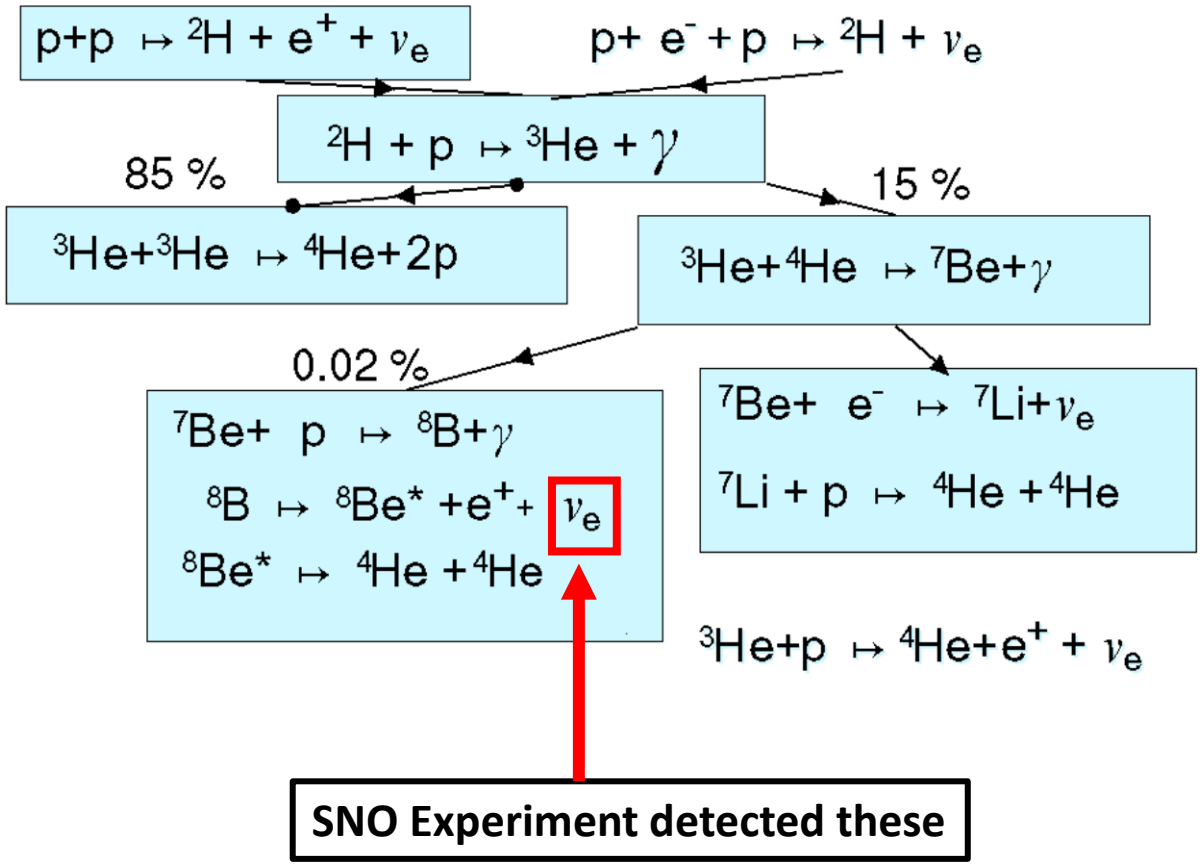


Sudbury Neutrino Observatory (SNO)

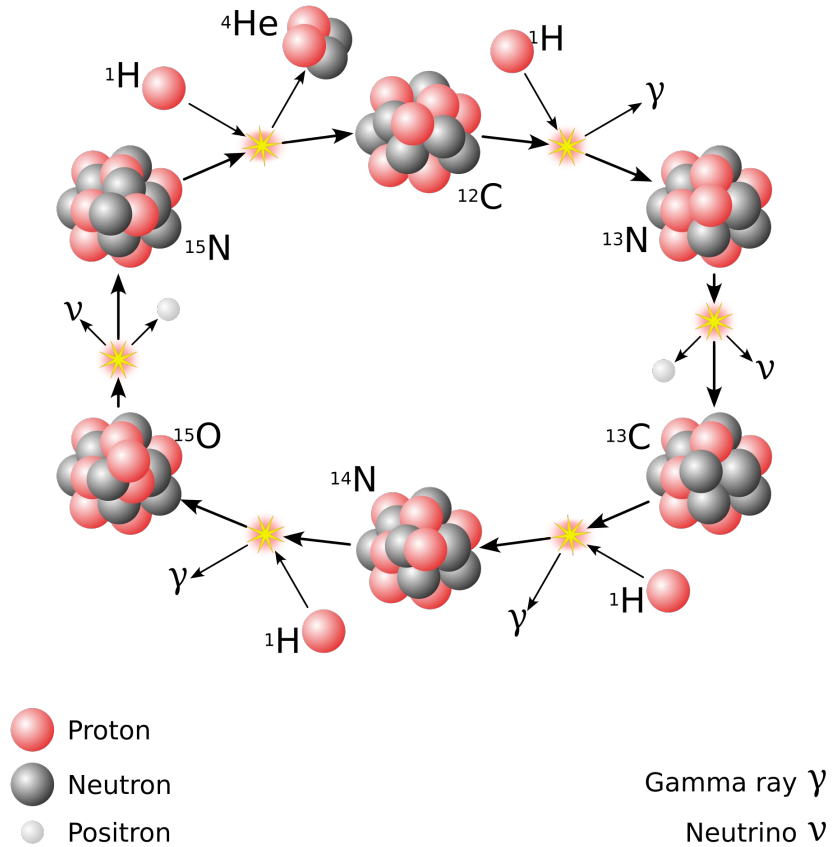


GENERATION OF ELEMENTS BY NUCLEAR REACTIONS IN THE SUN

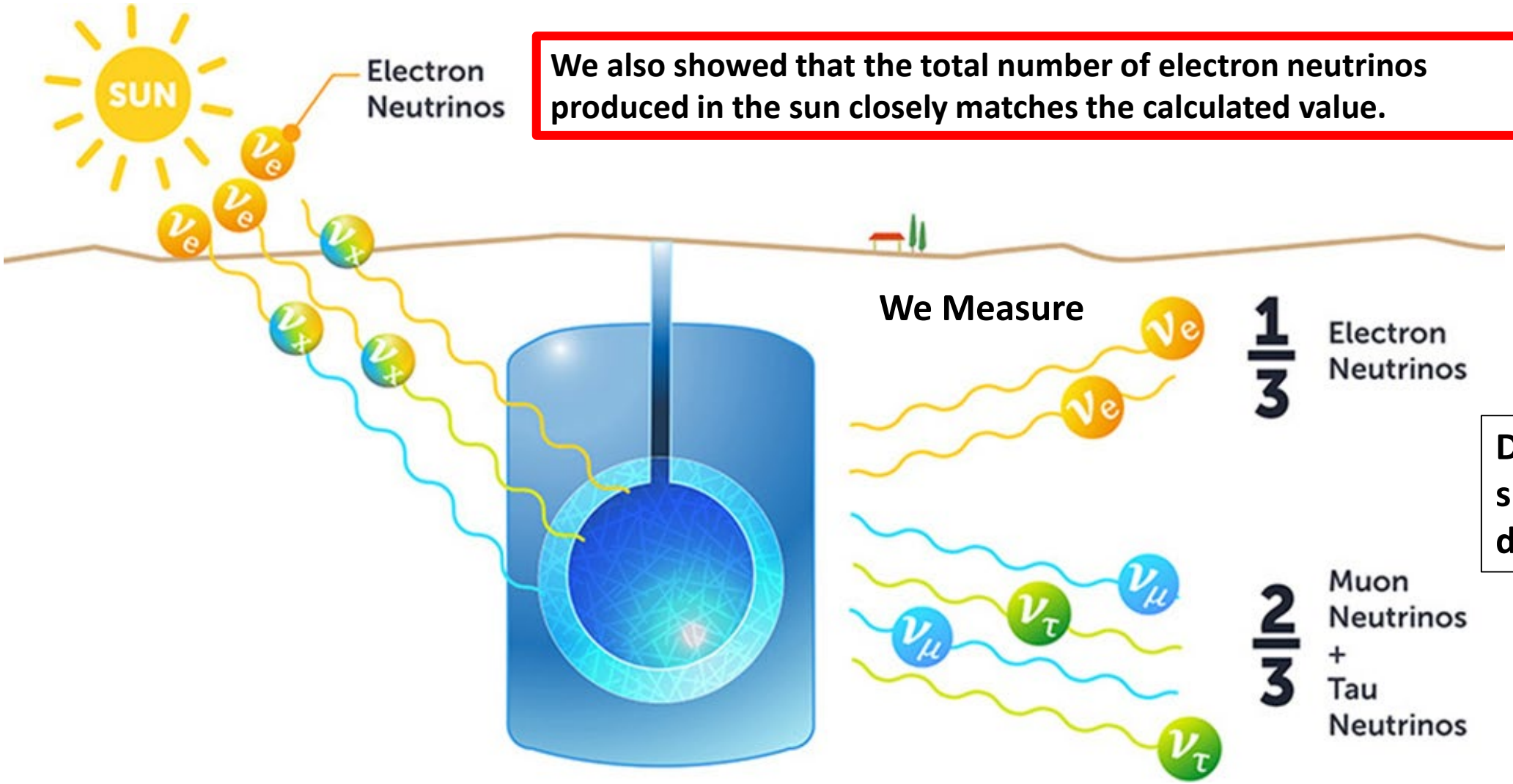
P-P CYCLE



C-N-O CYCLE



SNO: First discovery : Neutrinos Change Flavour and have a tiny mass



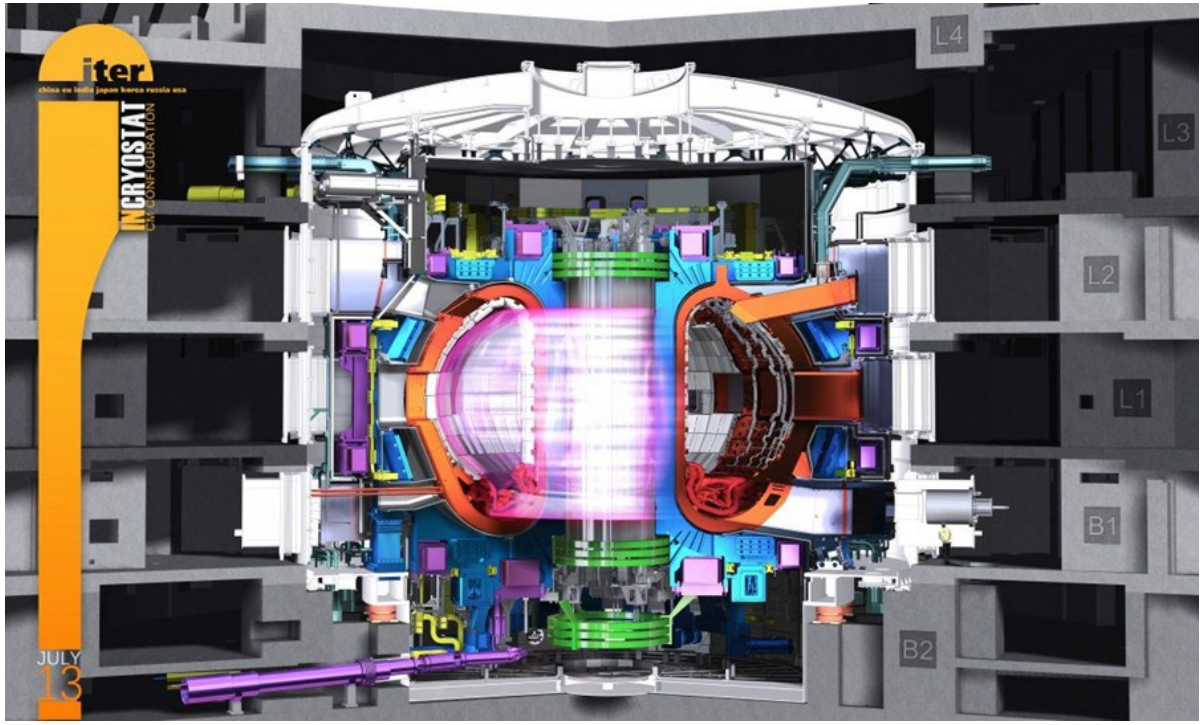
We also showed that the total number of electron neutrinos produced in the sun closely matches the calculated value.

Different signals in the detector

The Standard Model of Elementary Particles must be changed

Other Observations

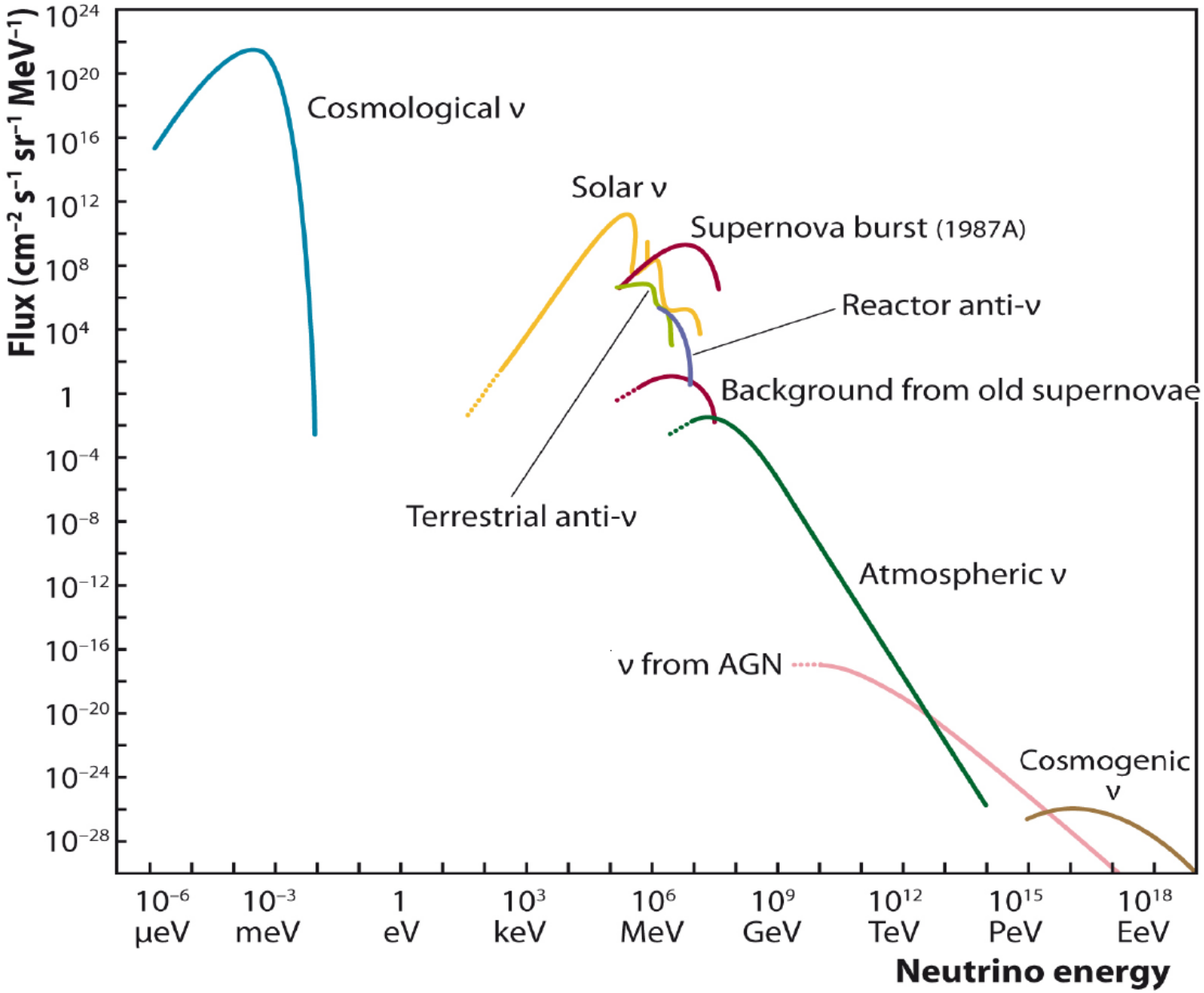
1. The SNO experiment accurately measured the number of neutrinos produced by fusion reactions in the sun, providing confirmation of the theory used to design Fusion Power reactors here on Earth.



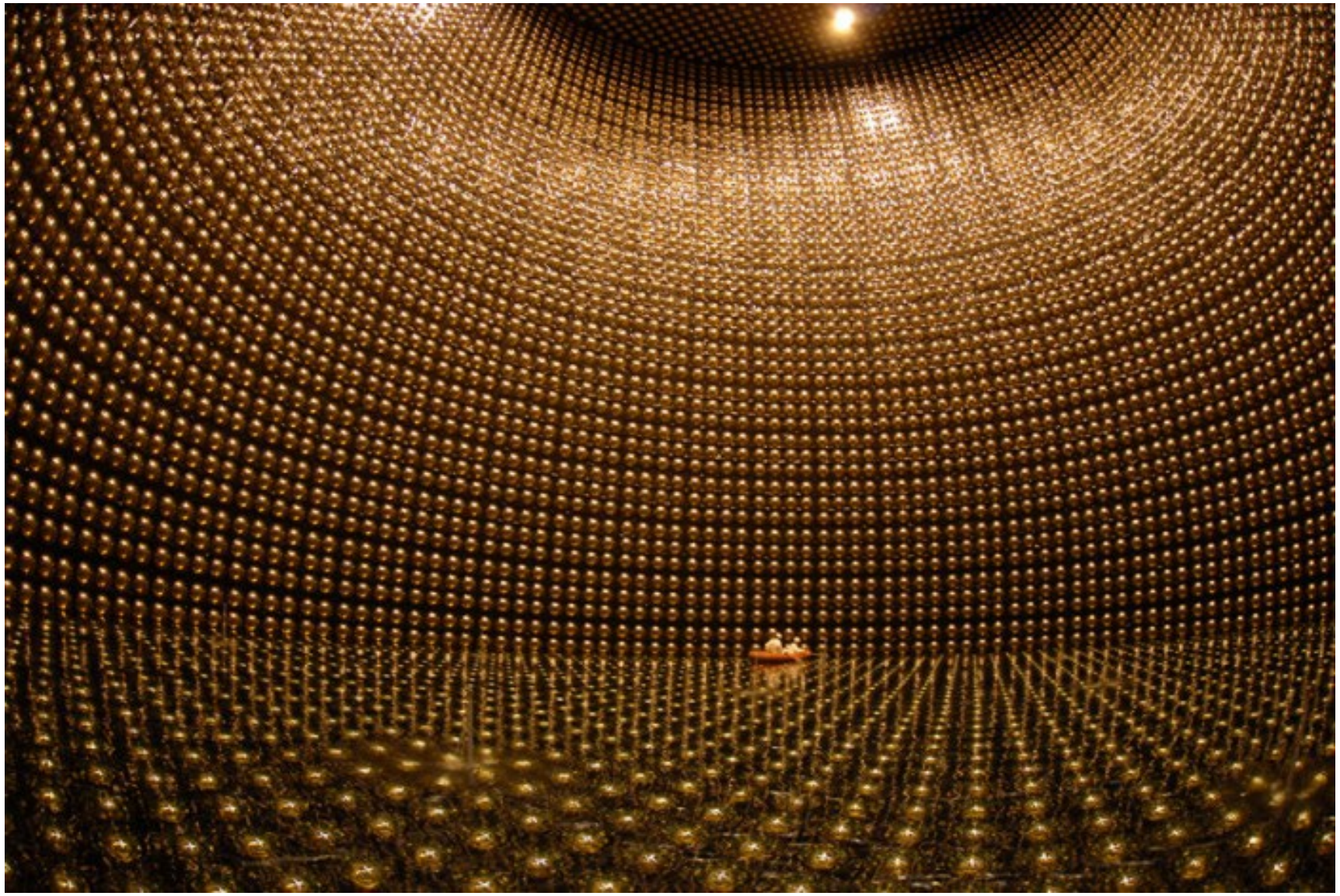
ITER: The Sun in a magnetic bottle here on Earth

2. The reactions producing the neutrinos in the Sun are the start of the sequence of reactions occurring in stars and supernovae that create elements from which we are made. (C, N, O..)

Neutrinos reaching the Earth



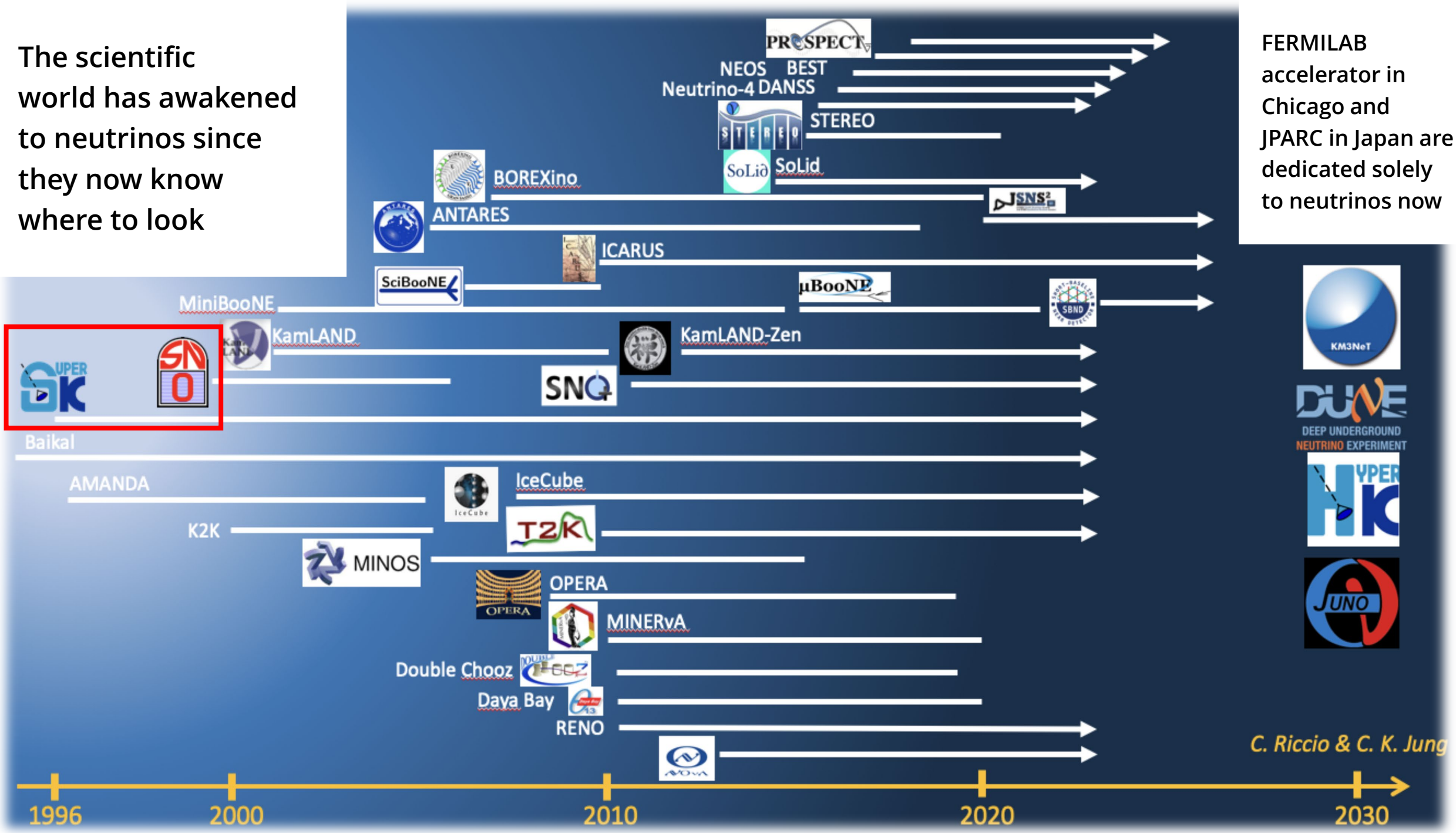
SuperKamiokande experiment – Japan



- **SuperKamiokande observed the oscillation of muon neutrinos produced by cosmic rays in the atmosphere.**

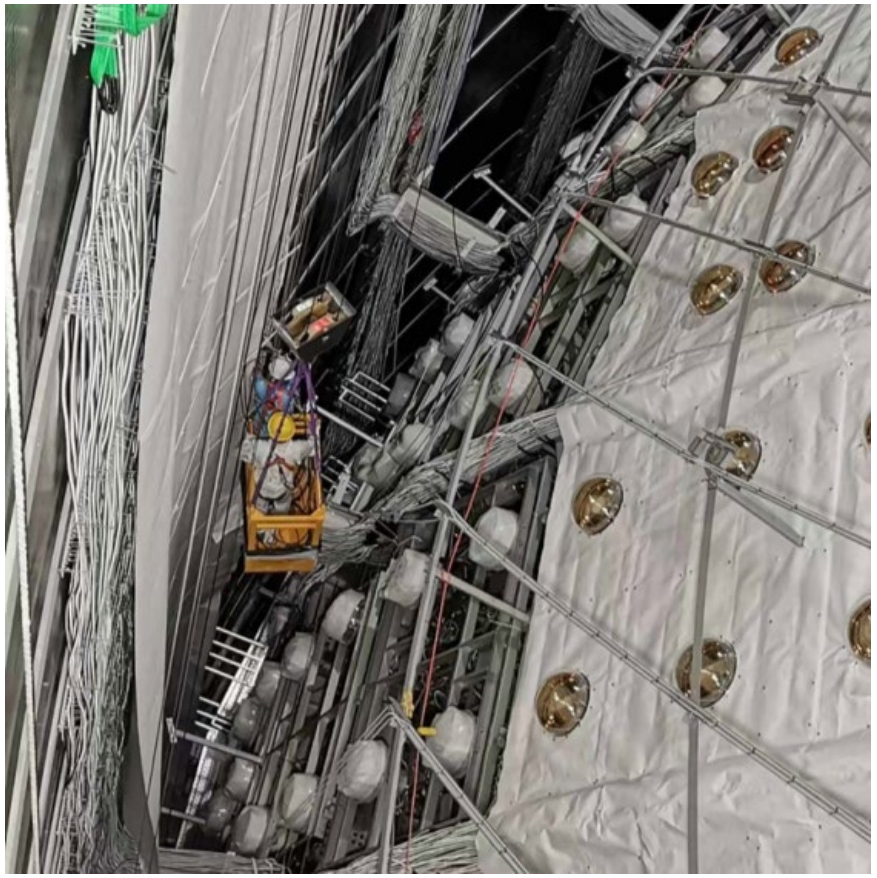
- **The 2015 Nobel Prize in Physics was awarded to Takaaki Kajita for SuperKamionande and to me for leadership of SNO.**

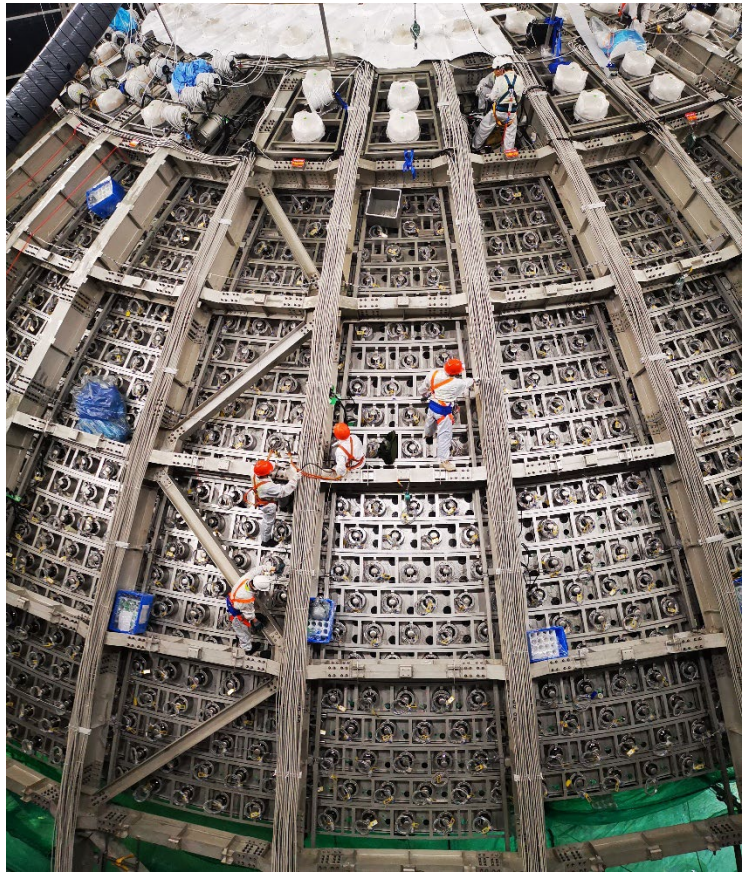
The scientific world has awakened to neutrinos since they now know where to look

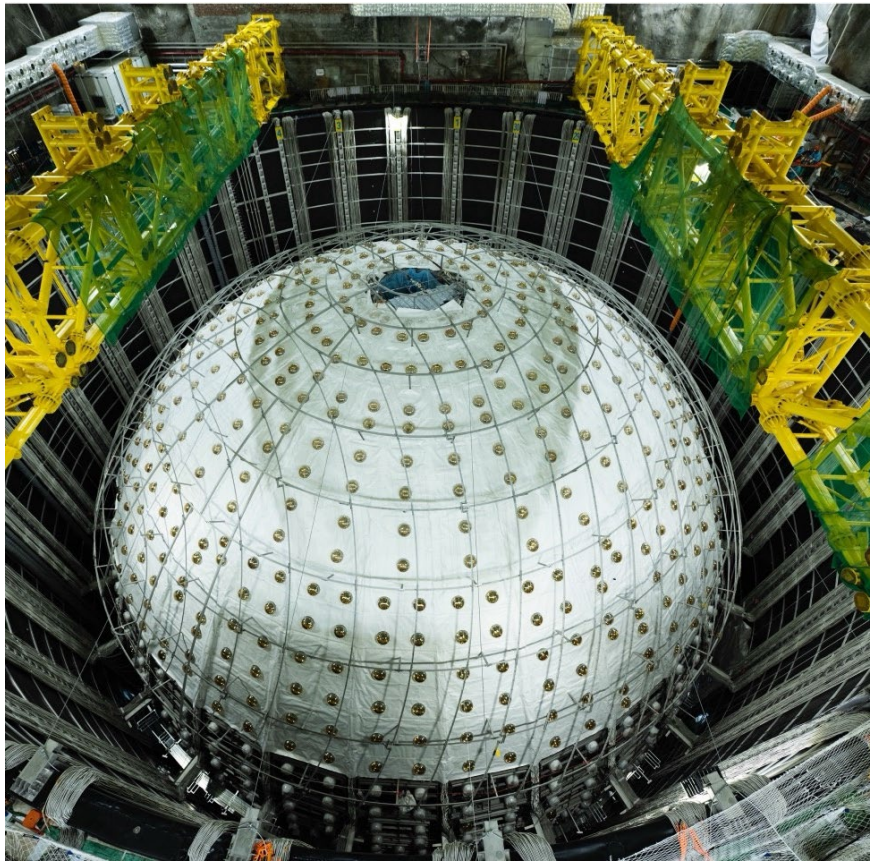


FERMILAB accelerator in Chicago and JPARC in Japan are dedicated solely to neutrinos now

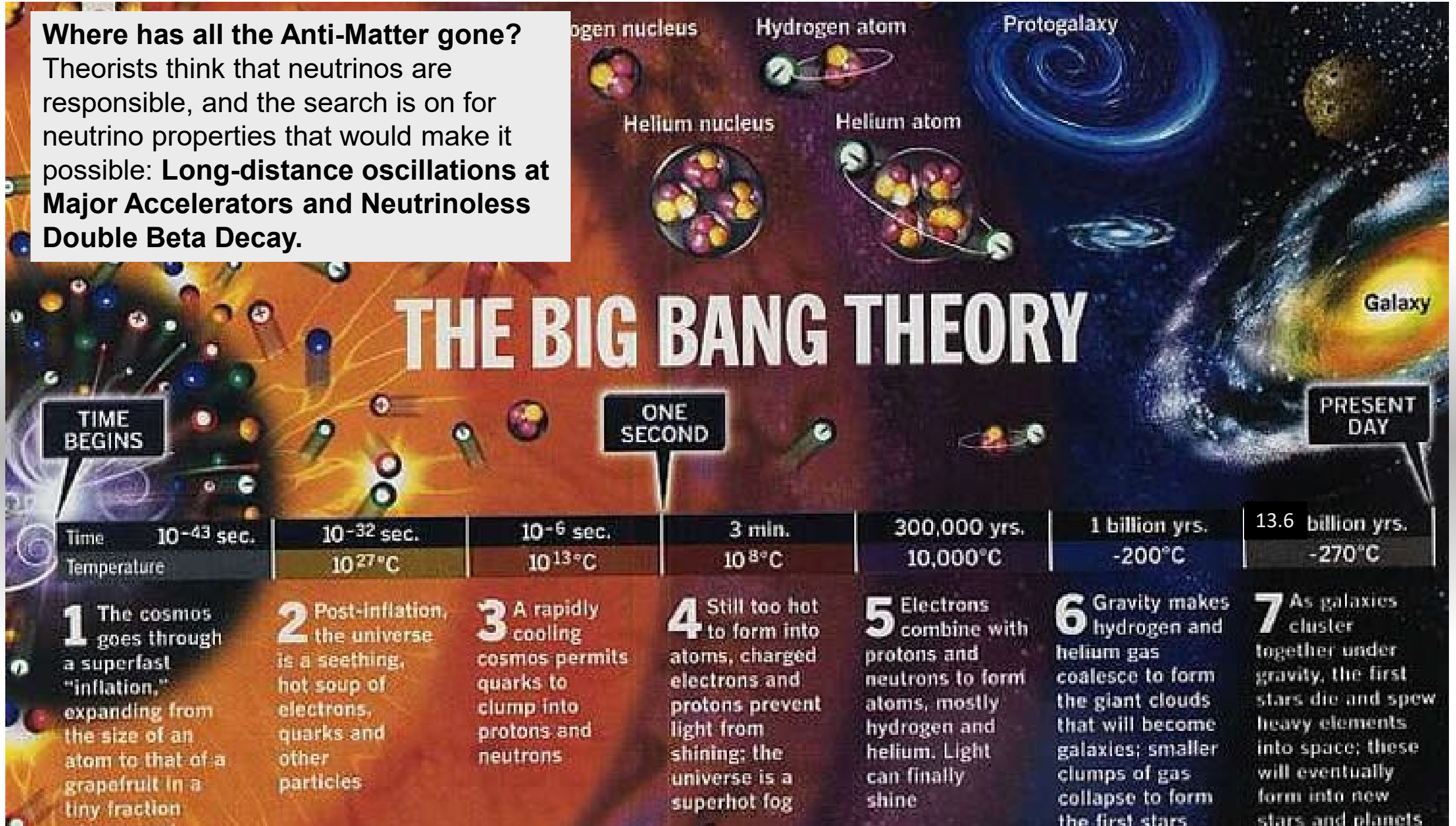
JUNO neutrino detector (China):
43m-diameter underground detector, 53 km from reactors.
Started running this year, principally to define the ordering of the neutrino masses







Where has all the Anti-Matter gone? Theorists think that neutrinos are responsible, and the search is on for neutrino properties that would make it possible: **Long-distance oscillations at Major Accelerators and Neutrinoless Double Beta Decay.**

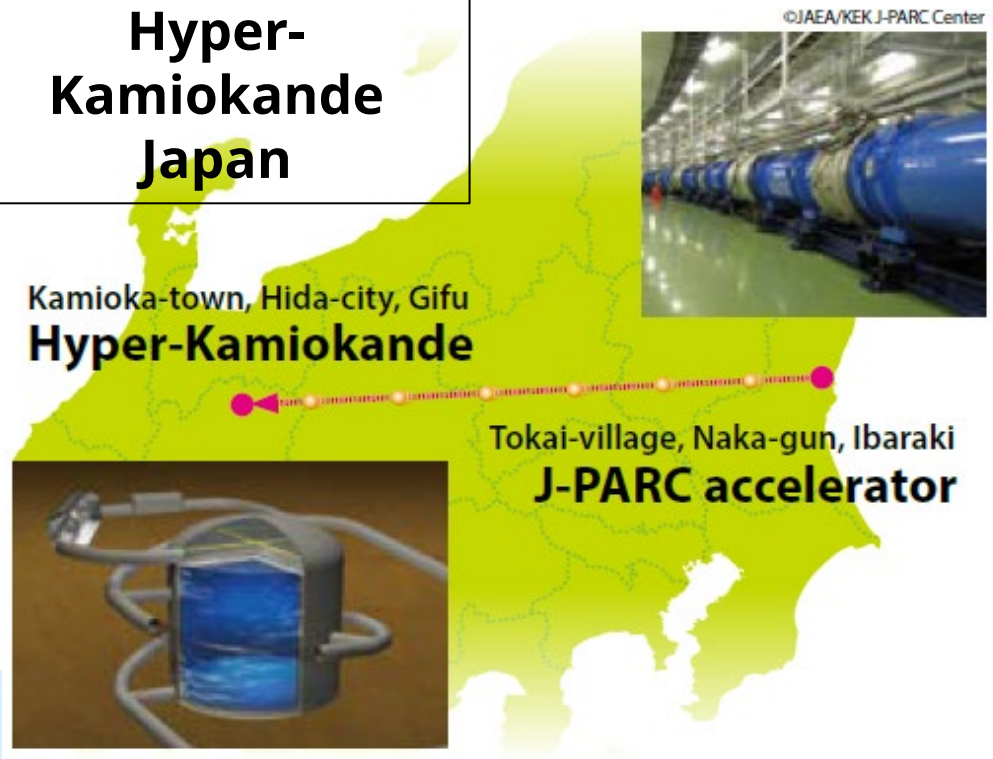


Future Accelerator Experiments

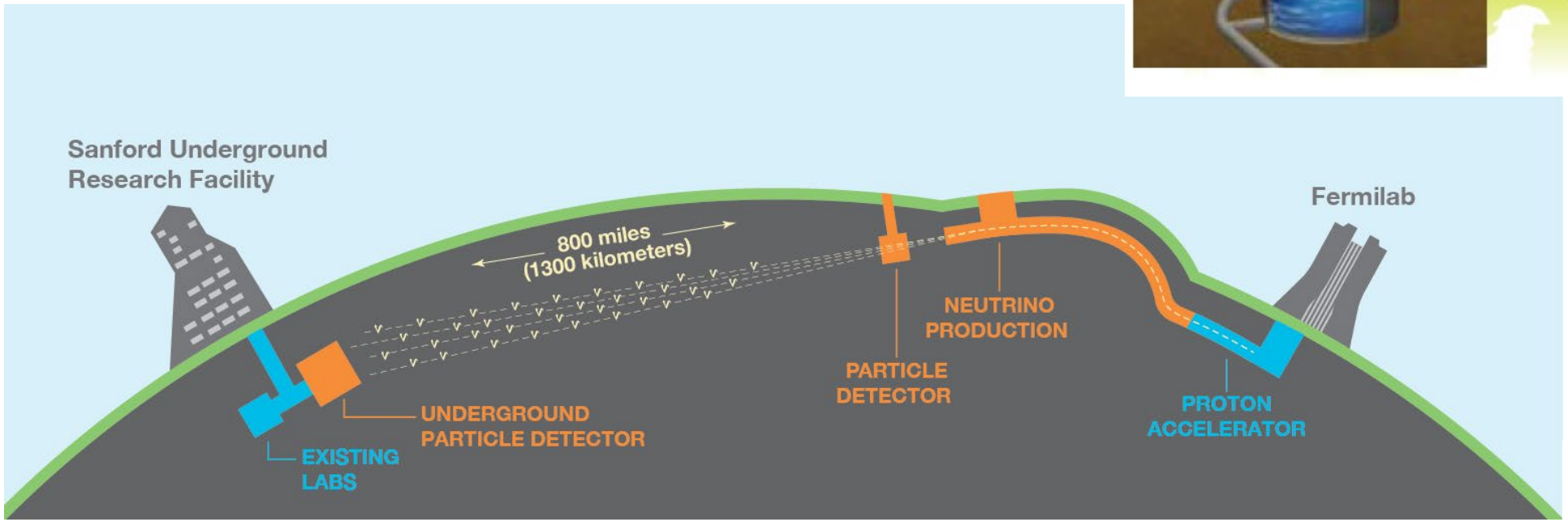
Compare neutrino oscillations initiated by muon neutrinos and their anti-particles.

Look for matter/anti-matter differences to understand anti-matter decay in the early universe.

Hyper-Kamiokande Japan

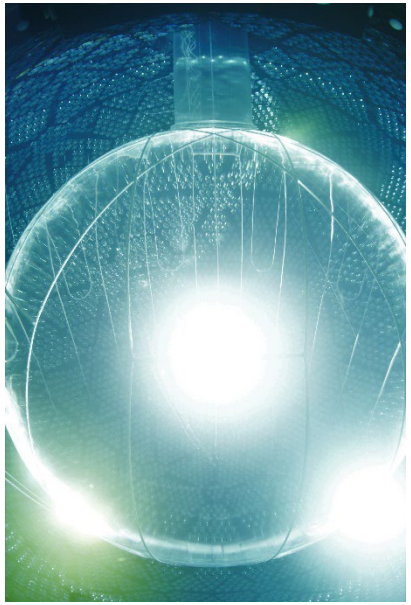


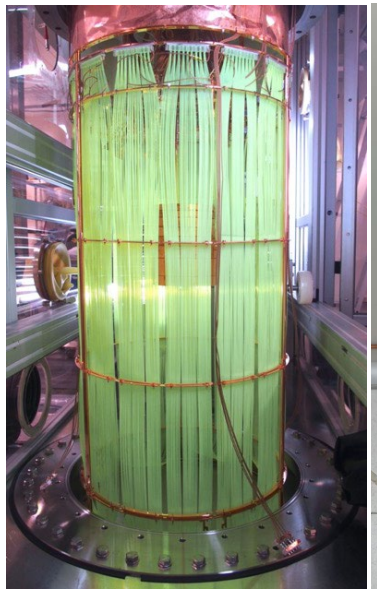
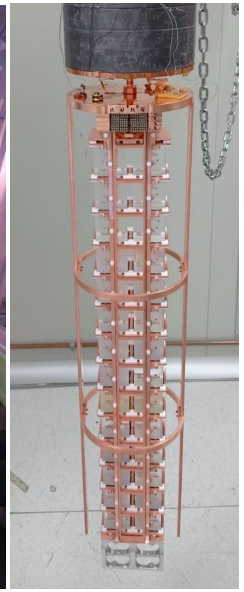
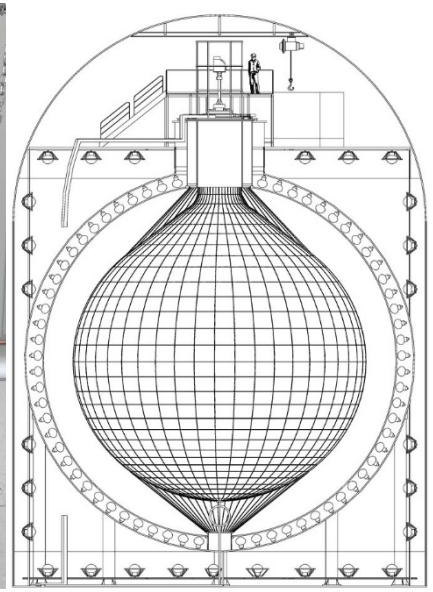
Deep Underground Neutrino Experiment (DUNE) USA



DUNE: 1400 scientists, 35 countries
HYPERK: 650 scientists, 23 countries

Neutrino-less Double Beta Decay



SNO+ (Te)
Canada

XLZD (Xe)
To Come

LEGEND (Ge)
Italy

CUPID (Mo)
Italy

KAM-ZEN (Xe)
Japan

- **If neutrinos are their own antiparticle, then a very rare radioactive decay can take place to observe this important neutrino property.**

- **Underground laboratories provide the lowest background radioactivity locations on earth to study such decays with lifetimes of > 10^{26} years.**

- **Sensitivity for such measurements has been improving steadily. There are several experiments internationally that will be ~10x the present size.**

Open Science and international cooperation have provided mankind with an excellent picture of how the Universe has evolved since the Big Bang.

Progress continues in measurements underground, in satellites and with telescopes on Earth to fill in the remaining details of these existential questions of our being.

This extraordinary example of INTERNATIONAL SCIENTIFIC COOPERATION WITH ONE PRINCIPAL OBJECTIVE should be an inspiration for world governments.

The PRINCIPAL OBJECTIVE that should motivate ALL GOVERNMENTS is WORLD PEACE!

McDonald Institute

Queen's University